

CFTRI-MYSORE



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Insects and hygi



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*Insects and hygiene*



### Capitulum. cxviii

**P**ulex. Ex li. de na. re. Pulices vocant  
sunt eo q̄ in puluere magis nutriunt.  
Pater pulicē esse vermiculū nigrū z  
minutū quidem, sed valde pūgitiūū. maxime



### Capitulum. cxix.

**P**ediculus. Isido. Pediculi sunt fmes  
cutis a pedibz dicti. vñ pediculosi dicti  
sunt dēto pediculi in corpore efferescūt



**P**vlex  
Ex li.  
bro de na  
turis rer.  
Pulices  
uocati  
sūt, eo q̄  
in pulue  
re magis  
nutriunt.  
Paret pu  
licem esse  
vermiculū  
nigrū  
& minu

tum quidem, sed valde pūgitiūū, maxi  
me autem tempore estiuo & pluuiāli. Salū  
unt autem potius q̄ uolāt, nocte q̄ die ma  
gis hominem infestant. Et nisi uehemens



**P**edi  
cul9.  
Isi. Pedi  
culi sunt  
uermes  
cutis: a  
pedibus  
dicti: un  
de pedi  
culosi di  
cti sunt,  
q̄bus pe  
diculi in  
corpore  
efferuesc

cunt. Ex libro de naturis rerum. Pediculi  
dicuntur a numerositate pedum: hoc ma  
lum ex ipsa hominis carne creatur indubi  
tante, & tamen inuisibiliter, hos nonnul

Woodcuts from the *Hortus Sanitatis* by Johann Prüss of Strassbourg. Above, from the 1491 edition; below, from the 1536 edition. Left, the sections on fleas; right, the sections on lice. Rather free translations run:

(Fleas) 'Pulex. From the book *de naturis rerum*. (i.e. Pliny). They are called pulices because they largely feed on girls (puluere). Fleas are tiny black vermin, but very aggressive, especially in summer and rainy weather. They leap rather than fly and infest man by night, rather than by day . . .'

(Lice) 'Pediculus. Lice are vermin of the skin . . . From the book *de naturis rerum*. They are called pediculi from the number of their feet (pedum); this pest is, without doubt, generated from the flesh of man himself, but invisibly . . .'

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# INSECTS AND HYGIENE

*The biology and control of insect pests of  
medical and domestic importance*

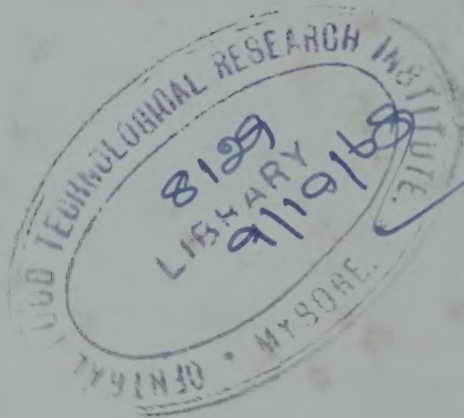
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Insects and hygi.

# *Preface*

## *Objects and arrangement of the book*

This book was written, primarily, for various technically trained people likely to be confronted with problems concerning insect pests of medical and domestic importance. For example, it may be helpful to Medical Officers of Health, Health Inspectors, Inspectors of the Ministry of Agriculture (Infestation Division), Commercial Pest Control Operators, School and Factory Medical Officers, etc.

In order to extend its use, it has been necessary to combine in the book some (entomologically speaking) elementary sections and other portions requiring some experience. Thus, Chapters 1 to 7 are introductory, intended to be read through by those without any special knowledge of insects, in order to gain an impression of their structure and way of life and of the general nature of insecticides, etc. Chapters 8 to 16 deal with specific types of infestation. In these chapters, the data are arranged systematically in sections (life history; quantitative bionomics; control, etc.) in order to facilitate searching for information on particular points. The Appendices are mainly for the benefit of trained applied entomologists who may find the book a convenient compilation of useful data.

## *Acknowledgements*

I am indebted to the late Professor P. A. Buxton, F.R.S., for his encouragement on my undertaking this work and for his kindness in reading and commenting on the opening chapters. In addition I have been fortunate in being able to submit various sections of the book to colleagues with more experience than myself in particular fields. The following is an alphabetical list of those who have been kind enough to read and amend appropriate chapters of my draft, for which I am very grateful.

Major H. H. Clay, Dr R. C. Fisher, Dr J. A. Freeman, Dr R. A. E. Galley, Prof. H. E. Hinton, Dr A. M. Hughes, Dr C. G. Johnson, Major H. S. Leeson, Dr K. Mellanby, Mr H. Oldroyd, Dr A. B. P. Page, Prof. A. D. Peacock, Prof. O. W. Richards, Dr W. S. Richards, Mr P. G. Shute, Dr J. Smart, Mr T. G. Tomlinson, Prof. Sir Vincent Wigglesworth.

In writing several portions of the book I have made considerable use of standard works of entomology, which may be rather too specialized for some of my readers. Although too much dependence on existing textbooks is to be deprecated, it would be over-scrupulous and inefficient not to make use of certain excellent monographs. The general classification and systematic notes are nearly all derived from Dr Imms' *Textbook of Entomology*. The bulk of Chapter 3 is based on Prof. Wigglesworth's *Principles of Insect Physiology*. Many of the keys given in the Appendix are based

on those in Dr J. Smart's *Insects of Medical Importance*. Other useful books have been Dr Marshall's *British Mosquitoes*, *British Bloodsucking Flies* by Edwards, Oldroyd and Smart, Professor Buxton's *The Louse*, Dr Kemper's *Die Nahrungs- und Genussmittels-Schädlinge und ihre Bekämpfung*, Prof. Hinton's *Beetles associated with Stored Products* and Mrs Hughes' *Mites associated with Stored Food Products*.

I am indebted to the British Museum (Natural History) for permission to reproduce Figs. 23, 32 and 42, and to the Oxford University Press for Figs. 27 and 28; likewise to the authors of the publications concerned. The remaining figures I have re-drawn from various sources acknowledged in the captions.

## *Preface to the Second Edition*

When I began the revision of this book, some 15 years after its first publication, it was clear that many changes and additions were required in the chapter on Insecticides, but the necessity for other amendments was less obvious. In fact, however, nearly every chapter has required substantial revision and an entirely new and larger chapter on chemical control measures has been written.

The general plan of the book has been little altered, but among minor changes is the removal of all authorities from specific names in the text; these are given only in the index.

Once again I must acknowledge the generous help given by various specialists; in particular Mr J. D. Bletchly, Mr G. A. Brett, Dr J. A. Freeman and Dr A. M. Hughes.

The more astute reader may notice that the words 'in Britain' have been omitted from the sub-title. My publisher and I feel that this is justified, since a very high proportion of the information in the book is relevant to temperate regions of Europe and North America, though it must, however, be admitted that a few sections (e.g. Chapter 5 or the parts of Chapter 9 dealing with mosquitoes) specially concern Britain.

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# I · *Insects and hygiene*

## I · INTRODUCTION

If numbers and variety are taken as the criteria of successful colonization, then insects are the predominant form of the land animal. It has been estimated that, despite their minute size, the combined bulk of the insects is about equal to that of all other land animals. Certainly they are the most varied, for some 600,000 species have been described, as compared with 10,000 mammals, 15,000 birds and 5000 reptiles. These figures are for known species; probably four or five times that number of insects await classification.

In the face of these figures, the number of insect pests is surprisingly small. A fairly substantial textbook on applied entomology, which mentions a good proportion of the more important pests, was found to contain less than 900 specific names. By far the greater number of harmful insects are those which attack plants or plant products. Man upsets the 'balance of nature' by agricultural operations, which result in unmixed crops and bulk stores of foodstuffs. Certain insects are provided with abnormally large supplies of food and, inevitably, they proliferate excessively and become pests. The losses caused by these insects are enormous.

Bloodsucking insects and other directly noxious forms are much fewer than agricultural pests; and the forms specifically adapted to man are probably less than a score. The reason is simple. Insects were rather a precocious group in geological history. At the time of the emergence of the first mammals, they were already the most successful arthropod group. By the Oligocene, when specimens were trapped in resins and fossilized as amber (about 20 million years ago) their evolutionary history was largely over. These fossils scarcely differ from their present-day descendants. The past 100,000 years, which saw the emergence of man, have been too short to attract the undivided attention of more than a very few insects.

Nevertheless, these specific parasites, and others which attack both man and other mammals, include the vectors of many of the serious epidemic diseases. The majority of these diseases are happily rare in, or absent from Britain, and therefore strictly beyond the scope of this book. However, they must be included in a brief review of the ways in which insects can be pests of hygiene.

## II · INSECTS AS PESTS OF HYGIENE

### (a) **Transmission of disease**

There are two ways in which insects spread disease. The simplest method is by mechanical contamination, which is usually an alternative to other means of transmission (drinking water, droplets or fomites, etc.). An insect, by reason of its habits, may carry germs from a source of infection to a healthy subject. If the contamination is external (on the feet or body of the insect) the risk of transmission often

declines fairly rapidly, because the infected matter soon dries, which destroys many germs.

Alternatively, the insect may swallow infected matter which is able to pass through its intestine undestroyed. Thus, infected faeces may be voided for a considerable number of days.

There are other diseases, with a more complex mode of transmission, which involve a particular insect or group of insects (or mites) as the sole means of dissemination. Usually the pathogen undergoes a special cycle in the insect, so that transmission does not occur until after an 'incubation' period. The pathogen may or may not be harmful to the insect.

#### (i) *Mechanically transmitted diseases*

##### *Enteric diseases*

A variety of unpleasant and dangerous enteric diseases can be transmitted by insects which visit infected human faeces and subsequently contaminate foodstuff. These include typhoid (*Salmonella typhi*), summer diarrhoea and dysentery (bacteria of the *Shigella* group) and cholera (*Vibrio cholerae*). By far the most important insect vector of these diseases is the common housefly. It is the most difficult insect to exclude from food in the kitchen and dining-room. Even in well-housed civilized communities in temperate climates, it is a common sight to see flies crawling over food and utensils. In modern towns with waterborne sewage, however, it is less easy for flies to gain access to human faeces and the risk of disease transmission is very much less than under primitive conditions. Nevertheless it is possible that flies are still responsible for a good deal of that serious disease of infants, summer diarrhoea. The close correspondence between the prevalence of houseflies and the infection rate during the summer in large cities was shown by much careful work in the first decade of this century.

Other insects which combine the dangerous habits of visiting both food and faeces include certain blowflies, fruit flies (see p. 180) and cockroaches. (The latter may visit drains or liquid excrement for water.) Such insects, as well as the more serious housefly, constitute an especial danger in hospitals, unless all septic matter is carefully eliminated at once.

##### *Sores and ulcers*

In tropical regions certain suppurative conditions are probably transmitted by flies. Trachoma, an infected, inflamed condition of the eye, often leading to blindness, is quite common in some areas such as North Africa. The causal organism can be carried to healthy eyes by flies, which frequently settle, unmolested, on the faces of children.

Yaws is a spirochaete infection causing disgusting skin eruptions. It is widely distributed in the tropics and especially on the west coast of Africa. Flies are believed to be mainly responsible for transmission.

(ii) *Exclusively insect-borne diseases**Malaria*

Malaria is caused by parasitic protozoa of the genus *Plasmodium*. As most people know, it is transmitted by anopheline mosquitoes. A vector mosquito takes a meal of blood from an infected person and the parasite undergoes development and multiplication within the insect. After a week or two (depending on temperature), the mosquito is able to infect further cases by its bite.

Malaria is probably the most important tropical disease. Over 1500 million of the world's population live in malarious regions; and in 1947, some 300 million suffered from it, about 3 million dying annually.<sup>(6)</sup> In the early days, malaria was controlled locally by suppression of mosquito breeding and by drugs (first quinine and later more efficient synthetic compounds). Recently, however, the fight against malaria has made great progress since the introduction of residual insecticides, giving lasting protection at low cost. These have made possible the campaign to eradicate the disease completely, initiated by the World Health Organization in 1948. It is based on the fact that man is virtually the only reservoir of *Plasmodium*; so that if transmission is halted until all cases are cured, the parasite will be exterminated. The progress to 1964 claimed eradication of malaria from an area with a population of 444 million and work still in progress in areas with a further 657 million; while 393 million still live in areas where the campaign has not yet started. Hopes of global eradication are still high, but it must be admitted that most progress has been made in the easier zones and that many formidable problems await solution.

*Mosquito-borne viruses*

( $\alpha$ ) Yellow fever is due to a virus transmitted by mosquitoes; it is endemic in tropical Africa and the neo-tropics. Some of the natives acquire immunity at the expense of attacks in early life, but it is a very dangerous disease to older non-immune people. In the serious urban epidemics, which have occurred in the earlier decades of this century, the vector was always *Aedes aegypti*. This domestic mosquito of the tropics is not difficult to control. Suppression of transmission, however, would not eradicate the disease (as with malaria) since there are reservoirs of the virus in monkeys of tropical forests. The infection could always be brought back to human communities, via sporadic cases round the margins of such forests. Hence the campaign against yellow fever in the neo-tropics (initiated in 1950) aims at eradication of the urban vector *Aedes aegypti*. Good progress has been made and it is hoped for a successful conclusion by 1966.

( $\beta$ ) Other virus infections carried by mosquitoes include dengue, an unpleasant but non-lethal disease in many tropical areas; also various encephalitides, present in animal reservoirs and sporadically carried to man or domestic animals in North America and Japan.

*Diseases due to haemoflagellates*

Three types of flagellate protozoan, alternating between vertebrate and arthropod hosts, are responsible for grave tropical diseases: *Trypanosoma*, *Schizotrypanum* and *Leishmania*.

( $\alpha$ ) Sleeping sickness, which is endemic over much of tropical Africa, is due to *T. gambiense* and *T. rhodesiense*. These trypanosomes are carried by various species of tsetse fly (*Glossina* spp.) as are related forms which cause the deadly disease nagana affecting horses and cattle.

( $\beta$ ) Chagas disease, occurring in many parts of South America, is due to *S. cruzi*, which is transmitted by bloodsucking bugs of the family Reduviidae.

( $\gamma$ ) The unpleasant and dangerous diseases kala-azar (due to *L. donovani*) and oriental sore (*L. tropica*) occur in many parts of the tropics. They are mainly transmitted by sandflies of the genus *Phlebotomus*.

### *Rickettsial diseases*

There is a group of febrile diseases caused by minute organisms known as rickettsiae, which alternate between parasitism of arthropods and vertebrates. Rickettsial diseases fall in the following groups:

( $\alpha$ ) The malignant epidemic typhus is due to *Rickettsia prowazeki*, which is transmitted only by lice, from man to man. Occasionally, when wars or other catastrophes have led to loss of amenities and to widespread lousiness, vast epidemics of typhus have caused great loss of life. Typhus is epidemic in parts of Asia and eastern Europe, but it has fortunately become extinct in western Europe. Since the introduction of powerful new insecticides such as DDT, typhus epidemics can be quenched by rapid and wholesale louse control.

( $\beta$ ) Tick-borne typhus, due to *R. rickettsii*, is found in both the New World and the Old World. In North America it is known as Rocky Mountain spotted fever; in South America as Sao Paulo typhus. In the Old World it is known by various local names. The disease is spread by various species of hard tick.

( $\gamma$ ) Scrub typhus, caused by *R. tsutsugamushi*, is sporadically distributed throughout south-west Asia. The rickettsiae are hereditarily transmitted by mites of the genus *Trombicula*, which only feed once on mammals in the course of their lives.

### *Plague*

Bubonic plague is caused by *Pasteurella pestis*. It is essentially a disease of rats, being transmitted from one to another by rat fleas. Occasionally it overflows to man, sometimes on an epidemic scale, being carried by certain rat fleas of the genus *Xenopsylla*, which bite man as well as rats. The liability of a community to plague therefore depends on the degree and type of rat infestation, the most dangerous form being the black rat, *Rattus rattus*. Prevention of plague can be accomplished by rat eradication; but during an epidemic, insecticides will be used against their fleas as well.

### *Relapsing fevers*

Relapsing fevers carried by arthropods are due to spirochaetes, especially species of *Borrelia*, which are primarily parasites of soft ticks.

( $\alpha$ ) Tick-borne relapsing fever due to *B. duttoni* occurs sporadically in many parts of Africa. It is transmitted by the bite of *Ornithodoros moubata*.

( $\beta$ ) Louse-borne relapsing fever is due to an aberrant species, *B. recurrentis*, which has become adapted to the human louse. It occurs in eastern Europe, North Africa and Asia. Like epidemic typhus, it is dependent on widespread lousiness and it can be controlled in the same way, by insecticides.

### *Parasitic worm infections*

The thread-like worms known as filaria live parasitically in the tissues of man and animals. They produce embryos which live in the blood or skin and are spread by biting arthropods, which serve as alternate hosts.

( $\alpha$ ) Perhaps the best known filariasis is due to *Wuchereria bancrofti*, spread mainly by the domestic mosquito *Culex fatigans* throughout much of the tropics. Some infections with this worm lead to occlusion of the lymph vessels, resulting in elephantiasis.

( $\beta$ ) Onchocerciasis due to the worm *Onchocerca volvulus* is spread by blackflies of the genus *Simulium* in Central Africa and the neo-tropics. The worm lives superficially in the skin, causing cutaneous lesions and in many cases eventually causes blindness.

### (b) Myiasis

By 'myiasis' is meant the lodging of living maggots in the bodies of men or animals. The tissues invaded may be the intestinal canal, various natural cavities lined with mucuous membrane or open wounds and sores. The maggots of various kinds of fly may be concerned. Some forms, known as 'bot flies', can only breed in this way; thus, certain Gasterophilidae pass most of their larval life in the stomach of horses and some of the Oestridae develop in the nasal sinuses of sheep and goats. Fortunately human beings are very rarely attacked by this type of parasite in Britain.

Other flies may be described as 'facultative' myiasis producers. That is to say, their maggots can develop satisfactorily in animal tissues, though they are not normally parasitic. These flies usually breed in carrion, but they occasionally infest open wounds or sores in living animals and feed on the necrotic tissue. Again, this condition rarely affects man in this country though many sheep fall victims to myiasis by sheep blowfly.

A third type of myiasis is the accidental invasion of the intestinal canal by various maggots which are swallowed with food (e.g. fly-blown cold meat). It seems that maggots swallowed in this way cannot develop normally, though they may not be rapidly killed. This type of myiasis naturally causes acute gastric disturbances such as vomiting and diarrhoea.

### (c) Poisoning, irritation and allergy

Many arthropods have developed poisoning mechanisms which they use either offensively, to paralyse their prey, or defensively against large animals such as vertebrates. The best known are the stinging bees, wasps and ants, the scorpions and certain spiders which inject venom with the bite. The poisons used may be as simple as formic acid (in certain ants); but usually more complex substances are

involved, apparently proteins of low molecular weight. The symptoms caused range from slight local reaction to acute neurotoxic effects, not unlike those caused by bites of poisonous snakes. Usually, insect bites are much less serious and only lethal to small animals; however, numerous stings can be dangerous to man and especially to children. Probably the most serious are the stings of bees and the bites of spiders of the genus *Latrodectus* ('Black-widow') both of which are responsible for a small number of deaths annually in certain countries.

Another chemical defence method used by insects consists of urticating hairs, rather like those of stinging nettles, which are found on a considerable variety of moth caterpillars. These larvae cause irritating weals if they are handled and considerably more severe symptoms if the detached hairs are inhaled into the respiratory tract.

Vesicating substances are present in the blood of certain beetles, especially those of the family Meloidae ('Blister beetles'). The fluid exuded if these insects are crushed, or even roughly handled, causes painful blistering of the skin. Presumably this is a defence against being eaten by birds or other insectivorous vertebrates.

*Allergic effects.* Insect venoms contain toxic proteins and these are liable to elicit the formation of antibodies. Therefore, repeated poisoning may cause anaphylactic shock. Bee stings in particular may be responsible for very severe effects, far worse than those due to simple poisoning.

Allergic reactions frequently occur as a result of the bites of various bloodsucking arthropods, though the effects are usually localized. The foreign proteins responsible occur in the saliva of the parasite which is injected into the wound during feeding.

Another type of allergy associated with mites and insects is a type of asthma due to inhalation of fragments of their bodies.

These different types of allergy can be observed in various stages. There are a proportion of naturally immune people; the remainder develop sensitivity to different degrees after the initial exposures; finally most of them eventually become desensitized.

Stinging and biting insects and the poisoning, irritation and allergies associated with them, are further discussed in Chapter 15.

#### (d) Disgust. Pathological cases (3, 7, 9)

Many household pests do very little harm but are regarded as highly unpleasant. Earwigs, woodlice and furniture mites are quite harmless and such pests as cockroaches and ants really consume very little food. Even the disgust caused by bed bugs or lice is not wholly alarm about the effects of their bites. The feelings of repulsion aroused by infestations of insects may be perfectly healthy instincts like the abhorrence of refuse and excrement. On such feelings are based high standards of hygiene.

Nevertheless, these feelings may exist in exaggerated pathological form associated with delusions. Nearly every advisory entomologist encounters one or two such cases annually. The afflicted person imagines his (or her) body or house to be infested with numerous invisible biting insects or mites. The sufferer experiences an anguished feeling of being unclean and persecuted. Advice is sought from chemists,

doctors or (by post) from popular newspapers and all sorts of preparations are tried without avail.

One type of sufferer characteristically brings 'specimens' to the laboratory, to prove the existence of the infestation. These turn out to be pieces of scurf or dirt, fibres or flecks from garments, small harmless insects, etc. The delusions are not easy to recognize immediately, except by an experienced entomologist, and not infrequently convince members of their own family. The sufferers are often people of intelligence, who talk rationally except in regard to their unshakable idea of being infested. The following extracts, however, reveal some of the delusions.

*Example (i) (from a man):*

Thank you for your letter. . . . You will like me, if possible, to send you a specimen of the parasite.

Even were the creature visible, it would still require ingenuity to catch one without squeezing it to pulp.

The creature is not visible and to me it appears to travel as fast as an atom.

However, I will smear some glue on a microscope slide and hold it close to my body in bed. With luck one of the creatures may be held by the glue. . . . I would say that the creature is smaller in size than the pores of the body. I often feel their bite on the flat part of the heel. The bite is sharp and intense. When I am still, I can feel their movements in my clothes. This gives rise to a most horrid and fearsome sensation.

The creature introduced itself to me when I lay on a dirty mattress during fire-watching. . . .

I saw a number of doctors the first two years. They could do nothing for me. Some of them said there was no such insects as I described. One doctor made up a liquid preparation which a druggist informed me contained oil of sassafras.

I tried DDT without effect.

It is possible that a large number of the creatures *are* killed by some of the substances I have used. But then the eggs hatch out so the condition is no better. . . .

*Example (ii) (from a woman):*

The house I moved to was very old and should not have been sold . . . gave me some stuff to burn; no good.

Then I found a nasty black insect that got under the skin and worried me nearly silly. I have tried everything, Lysol, kerosene, sulphur and carbolic acid. I had a blister as large as a dinner plate on my chest and cannot get rid of the horrid things in fact I have nearly *killed myself*. . . . I saw in the local Western Argus that 200 children were not fit to go to school also I had some books from the library full of nasty vermin, they were black. I wrote to the [a national newspaper] and they said it was a kind of skin trouble *lots* of people had written to them. They sent a 5% emulsion of Benzyl benzoate. I put some on my hair and find it affects my brain, I behave funny like I was drunk so I was afraid to use any more of it. . . . If you will advise me and let me know the *price* of your ointment I shall be *very very grateful*. I only wish I had never come to the dirty place (Kismet) the place should be burnt down . . .

The following points are noteworthy:

The sense of persecution.

The frequent attempts at self-medication, sometimes with unpleasant results.

Statements that 'other doctors' had been consulted.

Such characteristics strongly suggest the existence of what American authors have termed 'delusory parasitosis', though the possible existence of a real arthropod

pest should be checked. Thus, people have been suspected of such delusions when no cause was immediately apparent; but subsequent investigations have shown that there were real grounds for complaint. (In one case due to bites of *Culicoides*, in others to infestations of mites or even a dermatitis due to a kind of paint.)

The psychological causes of delusory parasitosis are beyond the scope of this book; but it may be noted that some kind of 'insect shock' is a common precipitating cause. Sometimes a real infestation (of lice, bugs or fleas) has existed and after it is cleared up the insectophobia remains. In other cases, talks, articles or films about insect pests may be responsible.

People suffering from this neurosis cannot be assisted by an entomologist and it does not really help to offer them insecticides as a placebo. The best course is to communicate with the sufferer's physician, or the local health department if this has become involved. Presumably these cases need a psychiatrist.

It may be mentioned that this type of neurosis is by no means confined to Britain; it has been noted in the U.S.A.,<sup>(4)</sup> Germany<sup>(3)</sup> and Hungary.<sup>(7)</sup>

### (e) Insects as destructive household pests

There are three ways in which insects can be destructive household pests. They may consume foodstuffs, they may damage clothing and other fabrics, or they may destroy woodwork. The pests responsible are dealt with in three subsequent chapters.

In the temperate climate of Britain, insect damage is less rapid and dramatic than in many tropical countries. But even partial damage may result in considerable loss, because food may be rendered unfit for human consumption by the presence in it of insects or their larvae or by the contamination of their excrement, silk webbing or peculiar smell. Again, the presence of a few small holes may 'ruin' a suit of clothes. Only the minor attacks of the furniture beetle are sometimes viewed with complacency, because they are supposed to guarantee antiquity!

## III · STATUS OF INSECT PESTS OF HYGIENE IN BRITAIN<sup>(1, 2)</sup>

### (a) Disease vectors

From the preceding sections, it will be evident that, in the tropics, the insects directly harmful to man by reason of stings, bites or other unpleasant qualities are much less important than those indirectly harmful as vectors of disease. In Britain, however, there now exist very few insect-borne diseases, partly due to our cool climate and partly due to improved standards of hygiene. Perhaps the only remaining potential disease vectors worthy of note are anopheline mosquitoes and flies.

Although indigenous malaria died out in England in the nineteenth century, there were small resurgences after the two world wars, as a result of the return from abroad of soldiers carrying the *Plasmodium*. After the first war, there were 481 confirmed indigenous cases; but only 34 after the Second World War.

The importance of the housefly as a vector of enteric and ophthalmic diseases in hot climates is undeniable; but in Britain its importance in this respect is dubious. Access to infectious human faeces must be extremely rare. On the other hand, there

is evidence that houseflies and blowflies may be heavily contaminated with *Salmonella* or *Clostridium*, especially if they have access to carcasses at slaughter houses.<sup>(4)</sup>

Suggestions have been made that blowflies (*Lucilia* spp.) may be a vector of poliomyelitis in temperate climates;<sup>(8)</sup> but there are considerable doubts about the possible chain of infection by this means.

### (b) Insects as pests of hygiene

Accounts of the range of insect pests likely to be encountered by a medical entomologist in Britain have been published, largely on the basis of ten years' advisory work in this field.<sup>(1)</sup>

#### (i) Indoor pests

##### *Parasites*

Lice, bed bugs, fleas and the scabies mite have been present in Britain for centuries; but only in comparatively recent times have we attempted to assess their incidence. During the Second World War, rather disturbing facts came to light during the evacuation of school children from cities (e.g. incidence of head lice infestations up to 50%). New remedial treatments were introduced with a thoroughness acceptable by people during national emergencies. The result was a sharp decline in arthropod parasites by the end of the war and the following years (see Table 1). One might, indeed, have hoped that the introduction of powerful new synthetic insecticides at this time might have enabled us to exterminate these pests. Unfortunately, however, the evidence suggests that the decline in incidence has ceased and there was even a suggestion of a slight rise of scabies in 1960.

Reasons for this failure may be twofold. Part of the trouble seems to reside in a small proportion of apathetic, ill-housed and ignorant people among the populations of large cities, who cannot or will not trouble to get rid of the vermin themselves. The other aspect concerns the health authorities, to whom the eradication of vermin often appears thankless and intractable, especially in comparison with other more urgent and topical problems.

##### *Houseflies and blowflies*

Houseflies can be very troublesome during spells of hot weather, though it seems that they are much less prevalent now that horses have virtually disappeared from our cities and they are forced to breed mainly in domestic refuse. Trouble still occurs from time to time in rural areas, especially near farms and poultry breeding houses. An increasing proportion of these infestations are due to the lesser housefly.

A curious form of sporadic nuisance is caused by 'swarming houseflies' of various outdoor species, which enter houses in some districts to hibernate.

Dipterous maggots are sometimes found in human faeces, vomit, etc., and may be sent by physicians or pathologists to an entomologist for identification. Another type of fly larva (or pupa) encountered is in dirty milk bottles; and other forms in cheese or ham.

TABLE I Data on various insect infestations from certain British cities

	1934	1937	1940	1943	1947	1950	1953	1957	1960	1963
<i>City A</i>										
Head lice										
(%) children infested										
Bugs: % houses infested	10.7	5.2	2.1	1.3	1.2	1.2	0.5	0.18	0.11	0.01
Scabies: No. persons treated	×	×	×	21,200	4055	353	354	1846	3451	1539
<i>City B</i>										
Scabies: No. treated										
Adults	×	×	623	16,685	4910	615	423	540	691	984
Children	×	×	316	10,715	2522	325	68	65	101	307
<i>City C</i>										
Bugs: No. houses treated	×	×	×	×	367	614	580	142	340	182
Fleas: No. houses treated	×	×	×	×	23	25	25	8	8	7
× Data not available or unreliable.										

*Kitchen pests*

The German cockroach and Pharoah's ant are particularly prevalent in centrally heated institutions and their common occurrence in hospitals is not without some risk of disease transmission, since they wander extensively and are very intrusive in their search for food and water.

*Larder pests*

A wide range of beetles and moths breed in stored foodstuffs and some make their way into domestic larders. Complaints often reach the local health department, who may have to decide whether a shopkeeper was to blame for selling infested food.

*Damp room pests*

Certain insects thrive best in a humid environment, either because they are very sensitive to desiccation or else because they feed on minute traces of moulds. They include silverfish, booklice, various small beetles of the family Cryptophagidae and furniture mites. The places infested include bathrooms, kitchen sinks, new rooms recently plastered and old damp store rooms.

*Garden invaders*

There are certain pests which are repeatedly found invading rooms from the garden. They include springtails (*Collembola*), carabid beetles, earwigs, crickets and the clover mite.

*(ii) Outdoor pests**Mosquitoes*

In Britain, as elsewhere, culicine mosquitoes are responsible for most of the annoyance from bites. Two types of habitat are involved. Low-lying marshy ground near the coasts of south-east England provide breeding grounds for two species of *Aedes*, which repeatedly cause annoyance to holidaymakers and others. Inland, biting mosquitoes are most troublesome in woodland, which provides suitable breeding places for about half a dozen species (mainly of *Aedes*).

*Biting midges*

Five species of *Culicoides* have been recorded as troublesome to man in Britain by their biting habits. They occur mainly in wild heathy country, especially parts of western Scotland, and the people affected are agricultural and forestry workers, as well as tourists.

*Other biting flies*

Blackflies (*Simulium*) occur in Britain but are seldom pests. Horseflies (*Tabanidae*) are troublesome locally.

*Non-biting insect swarms*

A warm spell of weather in summer may be the prelude to annoyance from large clouds of small insects. Various types of breeding ground can produce such swarms.

The filtering beds of sewage works are potential sources of small moth flies (*Psychoda* sp.) and non-biting midges (Chironomidae). Masses of rotting seaweed are breeding grounds of seaweed flies (*Coelopa* sp.). Small blackflies of the family Bibionidae can emerge in vast numbers from grassland. The identification of the insect causing the nuisance is the obvious prelude to possible control measures.

## IV. HISTORICAL NOTES ON INSECT PESTS OF HYGIENE

### (a) Ancient times

It is not surprising that the earliest references to noxious insects are vague, so that it is often difficult to be certain of the identity of the creature mentioned. Thus, one of the plagues of Egypt was described by the Hebrew word *Kinnim* which is usually translated as lice; but some modern authors believe sandflies or fleas were meant. Ancient literature was largely concerned with religious, historical or legal matters and references to insects were often mere metaphors or analogies.

... as a rotten thing consumeth, as a garment that is moth-eaten. — Job xiii. 28  
Go to the ant, thou sluggard . . . — Prov. vi. 6

Other early references are to beneficial insects; the silkworm (which was cultured in China in the third millennium B.C.) and the honey bee, which is mentioned in the Old Testament and by the ancient Egyptians. Descriptions of insects for their own sake are found first in early natural histories. The early Chinese encyclopaedia of Erh'ya (about 400 B.C.) refers among other insects to ants, bees, hornets, silverfish, biting flies and a kind of caterpillar with urticating hairs. The works of Aristotle (388–322 B.C.; 'Father of Natural History') contain a much wider selection of pest insects. This was further extended by Pliny the Elder (A.D. 23–79) whose Natural History was largely founded on that of Aristotle.

Very commonly, unpleasant insects were used in medicine, either internally or for external applications. This practice was very widespread and continued until comparatively modern times. There seems to be no special significance in this; many other horrid things have been used in primitive medicine.

Measures to prevent attacks of noxious insects advised by ancient writers are numerous and almost all useless. They include charms (amulets in ancient Egypt), minor rituals (burning of symbolic objects, as in China) and an enormous variety of herbs, minerals and animal products used as lotions or potions. Such abundance of useless advice resulted from the habits of thought based on observation and contemplation with contempt for practical experimentation. The empirical practices of folklore were often sounder than the recommendations of the sages, which were too often based on specious logic and insufficient data. Thus, the fancied resemblance of a flower or seed to a noxious insect would suggest to them that it would destroy that pest.

Among the many bogus remedies there are a few sound and valuable suggestions and practices. Herodotus records that the Egyptian priests shaved their bodies every

three days, dressed only in linen and washed frequently, in order to be entirely free from insect vermin. He also states that certain Egyptians living in marshes and much troubled by mosquitoes, slept under their fishing nets which kept off most of the insects.

In the Talmud and the Old Testament are many hygienic injunctions, some of them (as combing of the hair and frequent changing of the garments) being probably directed against insect vermin.

A beneficial practice, dating from early times, which was certainly based on empirical knowledge, was the draining of marshes to prevent malaria. Pythagoras recommended this in Sicily as early as 450 B.C.

The reason that empirical measures were most reliable in ancient times was because of fallacious ideas concerning the biology of the pests. Aristotle and his followers firmly believed in the spontaneous generation of insects. This was curious, in view of the fact that the ancients were familiar with the different stages of the insect life history; but they were unable to integrate them into a life cycle. It was thought that fly maggots were generated by dung or other putrefying matter. Aristotle mentions that some kinds of flies extrude live maggots; but these were presumed to be abnormalities. Again, lice were said to originate in small dry boils on the skin. The 'nits' produced by lice were known, but were regarded as a kind of excrement or else as a totally different form of life.

### (b) Middle Ages and Renaissance

During the Middle Ages, culture sank to so low a level that infestations of insect vermin became an unconsidered trifle of daily life. An indication of the usual state of personal hygiene is evinced in some rules for the deportment of the young nobility which deprecated the habit of cracking of lice or fleas in public. Morals and learning were in the hands of religious men who, striving against worldly luxury, were inclined to favour dirt and vermin as a sign of self-neglect. Thus, St Francis refers to lice as the 'pearls of poverty' and when St Thomas à Becket was murdered (1170) his undergarments were found to be seething with lice. The on-lookers were filled with a mixture of sorrow and joy; grief for having lost so great a leader, tempered with joy at the evidence of such saintliness.

Probably it was not until the seventeenth century that to be lousy was considered rather a disgrace. As late as 1645 Robert Hooke (in *Micrographia*) remarks about the louse: 'This is a creature so officious, that 'twill be known to every one at one time or another . . . so proud and aspiring withall, that it fears not to trample on the best and affects nothing so much as a Crown.' Fleas were certainly very common in high society in the sixteenth century and well-born ladies would wear round their shoulders a 'flea fur' supposed to attract and trap them. Fleas probably flourished in all houses until carpets replaced rushes as a floor covering. Classical learning, out of which modern science has been gradually and painfully evolved, was revived at the Renaissance. The idea of spontaneous generation was, of course, accepted (it is so plausible that even now it is often encountered among non-scientific people). Nevertheless, a few critical observers revealed the awkward facts that insects can be seen to copulate and lay eggs like higher animals. To discredit Aristotle required

much courage, and as a first compromise it was suggested that some insects have two methods of multiplication; one by 'generation' from putrefaction and one by copulation and reproduction. The simple experiments of F. Redi (1626-97) conclusively disproved the spontaneous generation theory of insect propagation, but were not widely known or accepted for many years.

Instructions for destroying noxious insects were multitudinous and quaint but seldom effective. However, we find a sprinkling of sound empirical advice. Thus, the *Book of Quint Essence* (1460-70), among such remedies as 'mercurie mortified with fastynge spottill' (fasting spittal) the observation that 'to withdryne them (lice) the best is to wasshe the oftentymes and to chaunge oftentymes clene linnen'.

A remarkable book published in 1634 gives an insight into knowledge of insect pests in Britain at that time. This is *Theatrum Insectorum*, the work of several sixteenth-century English physicians and divines, edited and enlarged by Thos. Mouffet, M.D., who, however, died forty-five years before it was finally published. An English translation was included in a natural history produced by Edward Topsell in 1658. Here are some extracts:

[From the chapter on lice]

It is a beastly creature and known better in Innes and armies than it is welcome. . . . The lice that trouble men are either tame or wild ones. [Apparently *Pediculus* and *Phthirus*.] The tame ones breed on corrupt Bloud and are lesse and reddish; from Fleame, white; from melancholly and adult humours, black; and from mixt humours, of divers colours. If you rub them gently between your fingers, you shall see them foursquare and somewhat harder than Fleas, whence in the dark you may easily find the difference. . . . As for dressing the body: all Ireland is noted for this, that it swarms almost with Lice. But that this proceeds from the beastliness of the people and want of cleanly women to wash them, is manifest, because the English that are more careful to dress themselves, changing and washing their shirts often, have escaped that plague. Hence it is that armies and prisons are so full of lice, the sweat being corrupted by wearing always the same clothes, and from this arises matter for their origin, by the mediation of heat.

[After giving innumerable remedies for use against lice, such as saffron, stavesacre, garlic, coriander, litharge, vinegar and oil, etc.]

I knew one, saith Pennius, when he was Governor of a Hospital cured the lowsie disease thus. He whipt the sick till the skin came off, with Birchin rods and where the prints were, the lice would never breed again: a new kind of cure and most fit for idle Sea-men and slothful companions.

[The 'nits' of lice are treated in quite a separate chapter under 'Insects without Feet']

Trotula, not improperly, calls them . . . hair-eaters, for as snails live on the juice of herbs, so these live on the moysture of the hairs and feed thereon. The philosopher affirms they proceed from the copulation of lice and therefore are called their eggs . . . as the Jesmine brings forth flowers without seed, so Lice bring forth eggs without young ones in them.

[Of 'wall lice' or bed bugs]

. . . They are bred, after Aristotle's opinion, from the moysture that sweats forth on the body of living creatures . . . but without doubt they arise from other humours corrupting about beds and that sweat out of wood by degrees. Also they propagate by copulation as Pennius observed at Orleans; for whilst he kept company with a Spaniard . . . he [? the Spaniard] strove to draw his sword to cut a bough, but when he could hardly do it for the

rust, he was forced to cut the scabbard where he found abundance of wall lice with a great company of young ones and a multitude of watery eggs. . . .

[Speaking of a suggestion that Carthusians were free of bugs because they ate no meat] . . . should rather have alleged their cleanliness and frequent washing of their beds and blankets to be the cause of it, which, when the French, Dutch and Italians do less regard, they more breed this plague. But the English, that take trouble to be cleanlie and decent, are seldom troubled with them.

[Of fleas]

Fleas are not the least plague, especially when in great numbers they molest men that are sleeping and trouble weary and sick persons. . . . Though they trouble us much, they neither stink, as Wall Lice, nor is it any disgrace to a man to be troubled with them, as it is to be lowsie. They punish only sluggish people, for they will remove farre from cleanlie houses.

[Of the garment-eating moth]

. . . a certain worm . . . that draws its coat along with it as a snail doth its shell [evidently *Tinea pellionella*] . . . it changeth to a chrysalis, out of which a little Glow-worm comes. This kind hanging by a thread, hangs a long time before changing into an Aurelia. [Pupa] It hath a little black head and the rest of the body a whitish dark brown. The case is made . . . almost of a Cobweb . . . lightly compacted. The phalænæ [adult moths] that come out stick by their feet to the roofs of houses until, their bodies being corrupted and putrified, they are bred again: their wings and feet are corrupted and fall off and they hang by their tails from a thread. At length they get a case and are turned into this kind of moth. . . . The richer people, as Horace writes

*Whose hangings rot in chests  
Rich for the worms and moths . . .*

take diligent care in summer to look up their garments and, taking them out of their coffers, air them in open places for the wind and then beat off the dust.

Thomas Mouffet was convinced that 'most bountiful Nature hath supplied us with a large field of Remedies', for all the various pests he described. As already mentioned, most of those he gives are valueless.

A more sceptical outlook was evident in the eighteenth century, judging from the 'Experiments to destroy Buggs in Houses' performed by Dr Boyle Godfrey and recorded in *Miscellanea vere Utilia* published in London (2nd ed. 1737).

This matter hath employed some ingenious men, for I met with a learned Professor of Physick and Chymistry who had labured in vain on the work for seven years. . . . As to all the Pretended Remedies or Cures against these vermin offered to the Publick daily and persuade myself they are nothing but Frauds: I let one of these Proposers do a Bed of mine, when, securing a little of his Liquor and examining it, I found it to be Yellow Arsenick and Oyl of Turpentine, which, if he could persuade the Bugg to eat would do; but I know he will march over that safely enough. The next famous Remedy that People spent their money on, was Oyl of Turpentine, Camphire and Spirits of Wine, equally to be laughed at . . . [After various experiments with Russia-castor, tobacco, pellitory, worm-wood and so forth] At last I tryed the following which no animal life can subsist under: *viz* Let matches of Sticks be made by dipping them in common sulphur so that they have adhering to them 4 lbs., which will do for some rooms [but others require about 6 lb] which matches must be set upright in a large Earthern pot . . . and set on fire in the Room where the Buggs are troublesome, stopping the Chimney by hanging Blankets before it and likewise . . . against the cracks of the Door. . . This sulphur, while burning will give a prodigeously strong Funk, and such as will kill all Creatures in the Universe. The work might

be commenced in the morning, and by next Day the Fume will be subsided. It would be proper to make the Fume when the hot weather comes on and they begin to bite; and again in September. All Gold and Silver Laces, Pictures etc., must be taken out of the Room, which, with other circumstances, renders it a troublesome work.

Another early English account of the bed-bug is *A treatise on Buggs* by John Southall, first published in London in 1730. Southall was enterprising enough to exploit the pest. He describes himself on the back page as 'Maker of the nonpareil liquor for destroying Buggs and nitts; living at the Green Posts in the Green Walk, Southwark.' The formula for the 'liquor', he wrote, was given him by an old Negro in the West Indies. It was sold at 2s. a bottle; but he also undertook to rid bedsteads of bugs with his own servants. His charges ranged from half a guinea for an elaborate bed, to 6s. for a simple four-poster.

In spite of the commercial outlook Southall's book was sufficiently comprehensive (one cannot say accurate) to attract the attention of Sir Hans Sloane, to whom it is dedicated, and who brought it to the notice of the Royal Society. It contains many inaccuracies. Bugs are credited with being able to live on dried paste and the sap of various woods as well as blood. Southall considered that the natural heat of the sun was necessary for hatching eggs and that this could not happen in winter. 'Although they are timorous and watchful,' he wrote, 'they fight fiercely among themselves, and often one or both are killed.' On the other hand, he included several interesting observations. One of the most significant of these is the statement that bugs were mainly confined to seaports and were therefore probably imported from abroad. He also states that after the great fire of London many bugs were imported in foreign timber. The 1793 edition of this book contains additional notes by a physician recommending three washes based on corrosive sublimate for use against bugs.

### (c) Modern developments

The recent history of the entomology of hygiene is far too extensive to be adequately treated here. Therefore, only a few notable facts will be given.

A common defect of the early writers, which handicapped their efforts at practical control of insects, was the prevalence of unsound ideas about insect biology, especially that of spontaneous generation. Complete eradication of a pest must have seemed hopeless, because the insects were supposed to be generated from boils in the skin, stale perspiration and other 'humours', rotten woodwork and various forms of putrefying matter.

The entomologists of the nineteenth century, however, benefited from the all-round advances in biology during that period. Among the earlier pioneers of that century, who laid the foundations of entomological science, may be mentioned the following. In Britain, William Kirby and William Spence, whose textbook was published in 1815, and Professor J. O. Westwood whose classification appeared in 1839; in America, Thomas Say 1787-1834 and Benjamin Walsh 1808-69; in France, P. A. Latreille 1762-1833 and J. B. A. D. Boisduval 1799-1879; in Germany, Ernst Tashenberg 1817-98. Such men, and their numerous successors, established the biological knowledge of insects upon which the only sound control measures are founded. The development of economic entomology as a science, a profession and

an industry is comparatively recent, largely within the past fifty years. A good account of its origins is given in a book devoted to the subject by L. O. Howard.<sup>(5)</sup>

#### (d) Insects and disease

It is now known that many dangerous epidemic diseases are transmitted through the agency of insects. This was far from apparent in early times when the causes of disease were little understood, even if the inquirer was not satisfied with the 'Judgement of Providence' theory. Nevertheless, we find scattered records of intelligent men who reasoned correctly from circumstantial evidence and deduced from clinical observations many things which have been later confirmed experimentally. Thus, de Sonza in Brazil (1587) and Edward Bancroft in Guiana (1769) each suggested that flies were responsible for disseminating tropical ulcer. Kircher, in *Scrutenium Physicomedicum* (1658) accused flies of carrying various other diseases and Montfils (1776) believed that they spread anthrax. In 1848 an American doctor, Josiah Nott of New Orleans, suggested that several tropical fevers were the results of mosquito bites, and in 1854, Daniel Beauperthay, a French physician in the West Indies, suggested that the germs of yellow fever originated in decomposing matter and were implanted into the human body by the bites of mosquitoes.

In spite of these intelligent guesses, no standard medical textbook gave any specific reference to insect-borne diseases prior to 1871. One of the earliest diseases proved to be carried by insects was a parasitic infection. In 1878 Patrick Manson, working in China, described the development of the nematode worm *Wuchereria bancrofti* in the body of a mosquito; and later, with other workers, he incriminated the mosquito of spreading filariasis. In 1895 Bruce established the fact that tsetse flies carried African nagana, the fatal disease of horses and cattle; and eight years later, with Nabarro, showed that they were responsible for sleeping sickness. In the meantime (1897) Ronald Ross announced the discovery of malarial parasites in the mosquito. Further elucidation of malaria transmission was due to Bastianelli, Bignami, Celli and Grassi in Italy, and the final proof was given by the experiments of Sambon and Low in the Italian Campagna.

In 1898 Simmond described the first experimental transmission of plague from rat to rat by fleas. This work was doubted at first, but later repeated and confirmed by Verjbitski (1903) and Liston (1904). At the turn of the century, the American Yellow Fever Commission in Cuba (Reed, Carrol, Lazear and Agramonte) proved that this disease is transmitted by the mosquito (*Aedes aegypti*). The carriage of dengue or breakbone fever was first ascribed to culicine mosquitoes by Graham in Syria in 1902. In 1906, Ricketts working in Montana, proved that the deadly Rocky Mountain spotted fever was carried by the tick *Dermacentor*. Louse-borne diseases were elucidated somewhat later; relapsing fever in 1907 by Mackie in India and epidemic typhus in 1909 by Nicholle, Compte and Conseil in Tunis.

The debt we owe to such men is not merely to their intellect, but to their courage, for such work is often dangerous and many of the early workers contracted and died of the disease they were investigating. Nearly all of them were medical men, whose attention was turned to entomology by the necessity of understanding and conquering a particular disease. At first it seemed to many people that insect-borne diseases

were practically conquered once their respective vectors were known. But many difficulties arose when control measures were attempted, demanding the knowledge and experience of a specialist. The first essential was a thorough knowledge of the comparatively small groups of insects which are responsible for disease transmission. Such studies were initiated by men like G. H. F. Nuttall. Careful classification and descriptions of the relevant genera and species were followed by elucidation of the life histories and habits. Subsequent investigations have involved statistics for population studies, and chemistry, physics and engineering for the use of insecticides and other control measures. As a result of these varied and highly technical requirements, a new profession has grown up in recent decades; that of applied entomology. Some idea of the scope of the subject may be gained from the chapters of this book, despite its relatively limited field.

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## 2. The structure and classification of insects

### I. IMPORTANCE OF CLASSIFICATION

When an insect is causing serious damage to food or crops, or where it may be a vector of disease, it is scarcely necessary to emphasize the importance of identification, which is the equivalent of diagnosis in medicine. It is very desirable that medical officers, sanitary inspectors, nurses and other people concerned with domestic hygiene should know about and be able to recognize common insect pests. As regards less common insects, the bare identification of a museum specialist will not convey anything unless something is known of their position on the insect family tree'. A little knowledge of the classification of insects will enable a person to utilize much information he already possesses. Like *le bourgeois gentilhomme* who suddenly discovered that he was able to speak prose, the student will find that he is already able to recognize several important orders of insects (such as the Coleoptera or beetles, the Lepidoptera or moths, the Diptera or flies, etc.).

The system of classification employed is the same as that adopted for other groups in the animal and vegetable kingdom, thus:

The insects form a large group of related animals called a *class*.

This class comprises a number of smaller, natural groups called *orders*.

Each order is made up of a number of *families*.

Each family contains a number of *genera*.

Each genus contains one or more *species*.

These groups are not arbitrary; they are based on the actual relationship of the insects, in so far as we can reconstruct their evolutionary pedigree. The more closely related species (i.e. those in the smaller groups) will show similarities, not only in appearance and structure, but also in their life history. As a rule, similar methods should be used to eradicate them if they develop into pests or nuisances.

### II. DEFINITION OF AN INSECT

In the first place, the definition of the insect class must be considered. Most of the pests to be considered are insects, though it will be convenient to include a number of mites and ticks which belong to quite a different class of animals. The difference may not be apparent to a casual observer. For example, it might be thought that a crab louse (which is an insect) is more closely related to an itch mite than to a butterfly. This is because the great differences in 'secondary' characters between the two insects is striking and obscures their common body plan which is shared by all insects, but not by other animals.

The body plan we consider fundamental because it was evolved first to cope with

daily problems of existence common to all animals (movement, respiration, digestion, growth, and so on). Secondary characters, such as size, proportion and colouring, are modified to fit animals for special environments. Thus the resemblance of crab louse and itch mite are superficial and due to their rather similar parasitic environment in or on the human skin.

Insects and mites are, of course, distantly related; they both belong to a huge group called the arthropods, which have stiffened jointed skins, forming external skeletons. On grounds of comparative anatomy, the arthropods are believed to have evolved from worm-like creatures with bodies composed of numerous similar segments, each bearing a pair of jointed legs, superficially rather like a centipede. In the course of evolution, improvements were made on this primitive type in two general directions:

- (1) There is an obvious advantage in a sensory control centre at the front end of the body and this region became specialized as a control centre, though not always as a distinct and separate head. Sensory organs (eyes, antennae, palps, etc.) were developed and some of the paired appendages of the anterior segments took over the function of jaws.
- (2) The second evolutionary tendency which has occurred in the more successful groups is an improvement in the body form to fit it for active locomotion. The primitive worm-like body was ill adapted for vigorous activity (especially on land) and several types arose from it with a more compact body and fewer, larger legs. The segments of the body, instead of being all alike, tended to become arranged in two or three groups subserving different functions; within these groups the segments often became fused together and in some traces of segmentation were lost.

The existing groups of arthropods are descended from ancestors which adopted body plans of different types which more or less efficiently met their primary needs. The principal classes are shown in the list on p. 21, which appends estimates of the total numbers of species known, in order to indicate their relative abundance:

The *Myriapods* are most similar to the hypothetical ancestors of all arthropods in their superficial appearance, but they have distinct heads bearing antennae and mouthparts. (Actually they are more specialized than they appear at first sight, the centipedes being fairly closely related to the insects.)

The *Crustacea* have evolved a twofold division of the body into a cephalo-thorax ('head-chest') and abdomen. The former bears sensory organs and mouthparts to form a head region and also five pairs of enlarged appendages for walking (in the higher forms).

The *Arachnids* adopted a fairly compact body form, with four pairs of legs and either one or two principal regions. The anterior portion is supplied with jaw-appendages and sometimes eyes; true antennae are absent, though certain palp-like appendages sometimes partly fill their place.

In the *Insect* class, the body is sharply divided (as implied by the name) into three regions:

	Classes	Orders	Nos of Species
ARTHROPODA	Crustacea	(Shrimps, lobsters, etc.)	24,750
	Myriapoda	Diplopoda (Millipedes)	1,300
		Chilopoda (Centipedes)	1,200
	Arachnida	Scorpiones (Scorpions)	600
		Opiliones (Harvestmen)	1,900
		Araneae (Spiders)	2,200
		Acari (Mites, ticks)	1,800
	Insecta	Thysanura (Bristletails)	325
		Collembola (Springtails)	1,250
		Orthoptera (Grasshoppers, roaches, etc.)	20,000
		Psocoptera (Booklice)	850
		Anoplura (Lice)	2,700
		Hemiptera (Bugs, aphids, etc.)	57,500
		Dermaptera (Earwigs)	900
		Coleoptera (Beetles)	250,000
		Hymenoptera (Ants, bees, etc.)	89,000
		Lepidoptera (Moths)	120,000
		Aphaniptera (Fleas)	850
		Diptera (Flies, gnats, etc.)	78,000

(Data from Metcalf & Flint)

*The head* (a fused mass of several segments bearing antennae and remnants of appendages adapted as jaws).

*The thorax* (three segments each bearing a pair of legs for walking and often bearing wings).

*The abdomen* (a number of segments containing the main digestive and reproductive organs).

If the variety and abundance of existing species be taken as a measure of their efficiency, it will be observed that the insect class is outstandingly successful. Several of its orders far surpass in numbers all the other terrestrial arthropods. (The crustaceans, which are the next largest class, are almost all aquatic and mostly marine; therefore, they will scarcely concern us in this book.) Of the myriapods, a few millipedes and centipedes are common enough to be well known to gardeners, but the only serious pests of hygiene occur among the arachnids. Here, they are practically restricted to the order Acari.

It is not unlikely that the dominance of the insects over other arthropods on land is due to their development of wings. Their expansion was accompanied by progressive evolution and differentiation which will provide the subject for the following pages.

### III · MAIN TYPES OF INSECT

We have now considered briefly how the insect class arose and why it is defined in arrangements of body segments rather than by colour, size or habits. To obtain

a bird's-eye view of the insects now existing, it is necessary to outline the evolutionary history *within* the group.

Fig. 1 shows the family tree of the insect class in diagrammatic form. The modern forms that have deviated least from the original type are shown at the bottom of the figure in a direct line from their ancestors. These are the *Collembola* or springtails and *Thysanura* or bristletails. All of them are fragile, wingless creatures. Their life history is simple; as in other animals, there are males and females which mate, and the fertilized females lay eggs. When the young hatch from the egg, they are miniature copies of the parents; they grow and moult throughout life, so that there is no very distinct adult stage. Underneath some of the segments of the abdomen are vestiges of appendages inherited from a primitive ancestor; most of these are absent in higher insects.

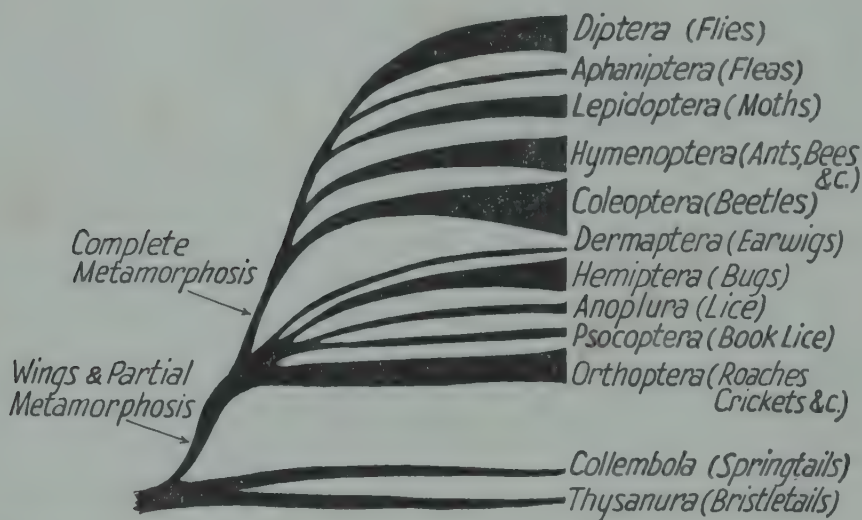


FIG. 1. Diagram illustrating the hypothetical relationships of the insect orders. (Only the orders represented by domestic pests are included.) Original.

Looking at the diagram one can see two distinct evolutionary steps within the group. The first great stride was made by the development of wings. The advantage which this gave to insects probably made them the most successful group of land arthropods. It must have occurred early in the history of the group, for some of the oldest undoubted fossil insects (from Carboniferous deposits 300,000,000 years old) apparently possessed functional wings.

Possession of wings is a troublesome matter for an animal which has to cast its entire skin in order to grow. But the benefit of increased range conferred by flying can be largely utilized by an adult insect which travels to colonize new areas for its progeny. Accordingly, there is no need for a young insect to be hatched complete with wings. Instead they can be formed later in life and, almost without exception, insect wings are only functional after the last moult.

In the first type of winged insect, the wings were formed slowly during growth and appeared as stumps in the young stages (called *nymphs*) and enlarge at each moult until the full size is reached. A life history of this sort is said to show *partial*

or *incomplete metamorphosis*. Modern examples are found in cockroaches, crickets, earwigs, etc.

The second major step in the evolution of insects was the emergence of a radical difference between the young stages and the adult. It was really an extreme specialization of the two periods of the life; the activities of the young were limited to feeding and growing, while the role of the adult was to mate, migrate and reproduce. The contrast in functions called for great differences in body-form, the young form or '*larva*' being scarcely recognizable as the same insect as the adult. The change from larva to adult involved considerable structural alterations, and it was accomplished in a resting stage or '*pupa*'. One life history of this type, which is known to every schoolboy, is that of butterflies and moths. Similar developments are shown by beetles, ants, bees, wasps and flies. These insects are said to undergo *complete metamorphosis*.

The general trend of evolution in the insect class is reflected in the main branches of its classification, the various orders being grouped as follows:

Sub-class (i) APTERYGOTA – (primitive wingless insects with no metamorphosis).

Sub-class (ii) EXOPTERYGOTA – (insects passing through partial metamorphosis. Wings developed as external stumps).

Sub-class (iii) ENDOPTERYGOTA – (insects undergoing complete metamorphosis with a pupal rest. Wings developed internally).

Unless one is making a special study of entomology, it is unnecessary to remember the names of these three divisions of the class; but it is important to remember that there are three different kinds of insect. For example, the difference between infestations of fleas and bed bugs can only be realized if the quite different life histories of these two pests are understood.

#### IV. THE ORDERS OF INSECTS

The trends in the evolution of insects which have been described may be considered as progressive, since they depend on two great innovations (the development of wings and the introduction of complete metamorphosis). Subsequent differentiation is more of a 'radial' or adaptive kind. Very broadly it may be said that after each advance, a variety of types arose which were able to exploit variations in the new ways of life. The pioneers who were successful founded the principal tribes of insects alive today. This is indicated in the diagram on page 21 by the branching of the main stems to form the various 'orders' of insects.

The natural orders are the bones in the skeleton of insect classification. A great deal can be inferred if an insect specimen can be assigned to its proper order; and this is not usually difficult. There are two guides which, used together, should enable anyone to recognize at least the principal orders of insects without extensive knowledge of entomology.

- (a) Insects, like other animals and plants, fall into natural groups similar in general appearance, so that typical specimens can be recognized at a glance.

These natural groups sometimes correspond to orders and sometimes to groups of families within an order. For example, almost all Lepidoptera (moths and butterflies) and most Coleoptera (beetles) can be recognized without much knowledge of entomology; similarly, Dermaptera (earwigs), Odonata (dragon-flies) and Aphaniptera (fleas) are mostly self-evident. Other orders may comprise several such well-known types. Thus, the Orthoptera includes the cockroaches and the grasshopper-cricket-locust type. The Hymenoptera includes sawflies, ichneumons, bees, wasps and ants. The Diptera includes the mosquito-midge type and the housefly-bluebottle type among others.

Something of the systematic relations of these types can be learnt by inspecting the diagram on page 21, which includes the principal orders of insect, examples of which are likely to occur as domestic pests in Britain. There are only about a dozen of them, and it is worth while learning their technical names. These scientific names are not merely specialists' jargon; they are much more reliable and precise than the common names. For example, the following names have been applied to cockroaches: 'black beetles', 'steam flies', 'croton bugs'; but as can be seen, they have no relation to true beetles, flies or bugs. (These terms also betray careless observation; 'black beetles' are brown, not black, and 'steam flies' rarely, if ever, can be seen to fly!)

- (b) The useful but rather unscientific method of guessing an insect's affinities by its appearance cannot be relied upon alone. For one thing, there are quite a number of insects which seem to mimic entirely different types; hoverflies that resemble wasps, clearwing moths that resemble sawflies and beetles that can be mistaken, at a glance, for spiders. So the preliminary guess must be reinforced by attention to certain critical features of structure. Most of the orders are characterized by fairly obvious anatomical peculiarities, and it is worth while learning some of these so as to be able to identify the principal orders with certainty.

In the following sections, it is proposed to describe briefly some of the more obvious external characters of the insect body and consider some of the variations of them which may be encountered. Stress will be laid on diagnostic characters.

## V · CHARACTERS OF ADULT INSECTS AND NYMPHS

### (a) General

#### (i) *Size, shape and colour*

The insects in some orders range from very large species to very minute ones. For example, the largest Coleoptera are twelve to fifteen centimetres long and the smallest are less than a half of a millimetre, when fully grown. The size of an insect, therefore, gives little help in assigning it to major groups. All that can be said is that members of some orders never attain large size. If an insect is a centimetre or more in length, it is unlikely to belong to any of the following: Collembola, Psocoptera, Anoplura and Aphaniptera (springtails, booklice, true lice and fleas).

The general shape of an insect may, as has been said, give a clue to its affinities. But shape is seldom a feature that can be used for precise definition of large groups. It is interesting to note, however, that certain parasitic groups tend to be flattened (i.e. thin and narrow as in fleas, or wide and flat as bugs and lice). The 'wasp-waist' is a characteristic shape of a large group of the Hymenoptera.

Colour is too variable and indefinite a character to be of help in defining large groups like orders and is often unreliable for even specific identifications.

(ii) *The number of segments*

The insect head is superficially unsegmented and the thorax is always composed of three segments, but the number of segments present in the abdomen is variable. The primitive number is eleven and these are all present in Thysanura (bristletails). Other orders exhibit more or less reduction.

Unfortunately this character is not always very simple to employ in identification because some segments are often present in a very reduced condition and are therefore difficult to make out.

(iii) *Character of the integument*

The 'skin' of an insect (which is quite different from the skin of vertebrates) consists of a more or less stiffened cuticle. Some groups are characterized by a thick and rigid cuticle, while others are generally more soft and fragile. For example, the Thysanura, Collembola, Lepidoptera and several other less important orders, are generally rather soft-bodied insects, while the Coleoptera and Orthoptera are notably well armoured as a rule.

The stiffer cuticles are often sculptured into ridges and pits and sometimes form sharp projections or spines. The latter are often present on the legs (especially of Orthoptera) and presumably give purchase for running or jumping on rough surfaces.

A closer examination of the integument will usually reveal fine hair-like projections known as 'setae'. These may be quite sparse, in which case the position of each one is usually quite definite and may be used as a diagnostic character for the particular species. Alternatively they may form a dense mat all over the body. In the Lepidoptera they are flattened to form minute scales which rub off as 'dust' when the insect is handled. Setae modified as scales are also found on certain Thysanura ('silverfish') and on mosquitoes.

(b) **The head and its appendages**

(i) *Antennae*

Like most other parts of the insect body, the antennae are capable of a remarkable range of variation. The primitive form consists of a large number of nearly similar segments tapering to a point. This kind of antenna is found on all the earliest insect fossils and on some of the least evolved orders alive today (e.g. Thysanura, Orthoptera).

The simplest modification of this type is by reduction in length. There is a general trend towards reduction in number of joints in all higher insects and, in

addition, various kinds of specialization of the individual segments. From being a series of ring-like joints, they may simulate jointed rods, clubs, or a row of various sized beads. By development of projections on each segment they may become comb-like; or numerous setae may give a feathery or brush-like appearance.

These very specialized developments, however, are seldom characteristic of large groups. There may even be a great difference in form between the sexes (as in many Lepidoptera and lower Diptera).

### (ii) Eyes

Two types of eyes occur in nymphal and adult insects – simple and compound.

The *simple eyes* are seen as small lenticular swellings on the top of the head. When typically developed, there are three of them arranged in the form of a triangle.

The characteristic of the more obvious *compound eyes* is the faceted appearance of the cornea (or transparent covering cuticle) which is quite visible to the naked eye. The number of facets varies very greatly in different species – from under a dozen to over 15,000. The size of these eyes and the number of facets are obviously related to the demands for accurate vision made by the way of life of the insect. In general, therefore, active, flying forms have large eyes and many facets (Lepidoptera, Diptera) compared with more pedestrian types (Coleoptera). At the other end of the scale are forms living retiring or else parasitic life to a large extent in darkness. These have poorly developed eyes or sometimes the compound eyes are absent (e.g. Thysanura, Collembola, Psocoptera and the parasitic Anoplura, and Aphaniptera).

### (iii) Mouthparts

It may be remembered that the ancestral arthropods are presumed to have had bodies composed of segments on each of which was a pair of legs. Their insect descendants have discarded most of these appendages and only retain three pairs for walking. But some of the anterior ones, on the head, have been preserved in a greatly modified form, to serve as jaws (or more accurately, mouthparts).

If it is very hard to believe that an animal can use its legs as 'jaws', the theory can be rendered more plausible by examining a lobster or crab. These large crustacea are distantly related to insects and their mouthparts have not become quite so specialized and changed from the original form.

Insects take a great variety of foods in many different ways. The primitive forms bite and triturate solid particles; but, among higher forms, some lick up juices, some pierce plants and suck sap and others puncture the skin of animals to suck blood. Naturally, these different modes of feeding require very considerable modifications on the feeding equipment of the primitive biting insect. By an extraordinary range of variations, this apparatus is adapted for chewing, stabbing, sucking and licking the various forms of food. Though they are less evident, because of the small size of the mouthparts, these modifications are almost as important as the wings as a guide to the different orders. By examining the head of an insect under a strong hand lens, it should be possible to recognize the three main types of mouthparts, especially if they are teased out with a needle.

The feeding equipment of the primitive insect was the following:

Upper 'lip'

(Appendage pair 1) Stout, biting, tooth-like;

(Appendage pair 2) Jointed appendages with teeth and bristles for tearing and manipulating;

(Appendage pair 3) A pair of fused appendages forming a lower lip;

A tongue-like *hypopharynx* is also present in some insects.

Labrum  
Mandibles  
Maxillae  
Labium

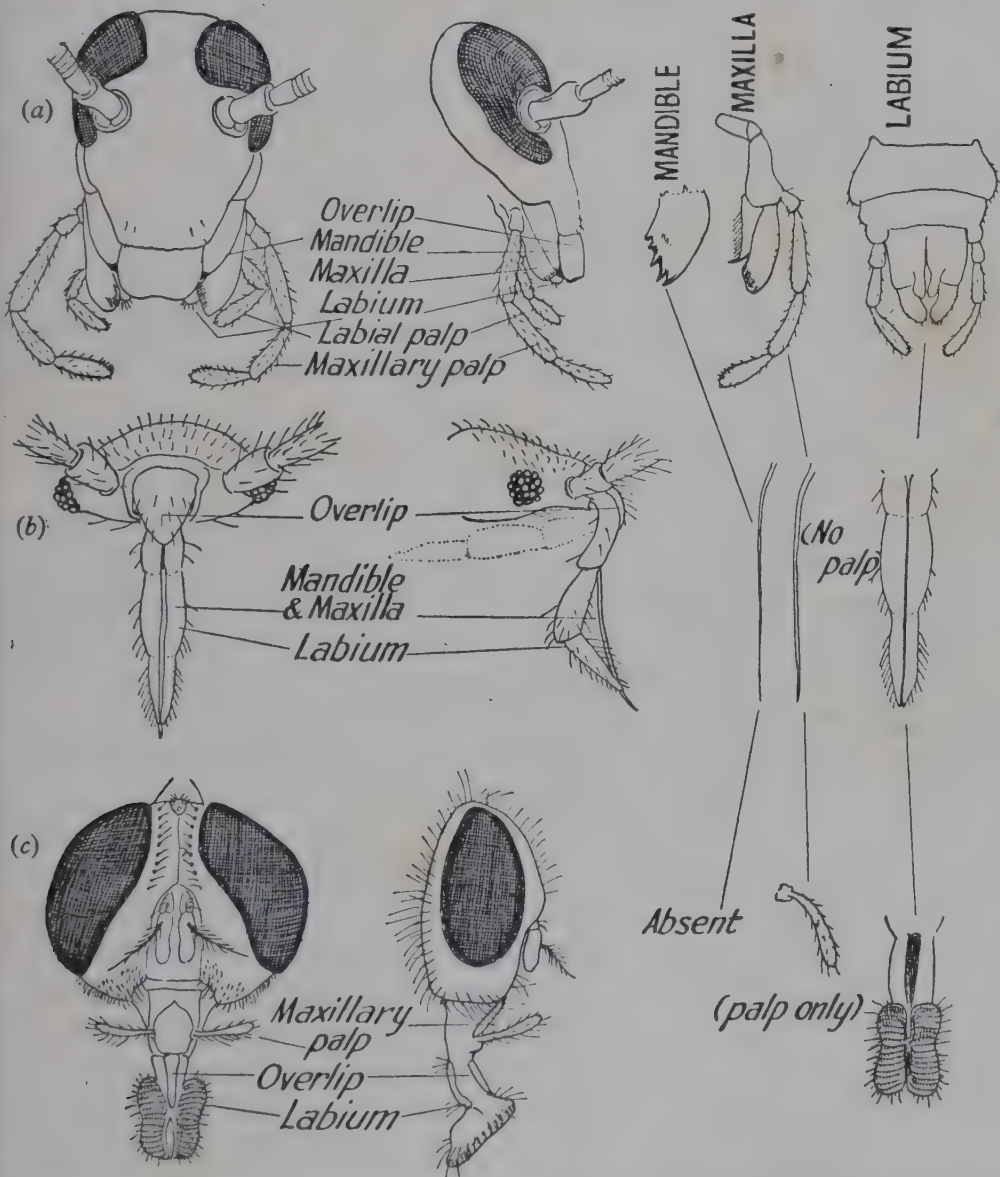


FIG. 2. Insect mouthparts, illustrating specialization of the parts for different methods of feeding. (a) primitive biting type (Cockroach); (b) a piercing and sucking type (bed bug). Note, modification of mandible and maxilla to form stylets and the loss of palps; (c) a licking type (housefly). Note, loss of mandible and maxilla (except vestigial palp) and modification of lobes of labium. (a) and (c) after Patton; (b) original.

Each maxilla and the appendages forming the labium bore a short jointed finger-like feeling organ or *palp*.

Three principal types of mouthparts can be recognized by the state of development of the mandibles:

- (1) *Biting types*. (Mandibles well-developed tooth-like structures). e.g. Thysanura, Orthoptera, Dermaptera, Psocoptera, Odonata, Coleoptera, Hymenoptera.
- (2) *Licking types*. (Mandibles vestigial or absent; sucking tubes or pads formed by other parts). e.g. Lepidoptera, and certain Diptera (as the housefly).
- (3) *Piercing and sucking types*. (Mandibles, and often other parts, formed as piercing needles, usually protected by a proboscis-like labium). e.g. Hemiptera, certain Diptera (mosquitoes), Aphaniptera.

Two exceptional cases may be noted where the mouthparts are withdrawn into a cavity in the head: the Collembola (biting type) and Siphunculata or sucking lice (piercing and sucking type).

### (c) The thorax and its appendages

#### (i) The wings

The most obvious diagnostic character about the wings is their presence or absence. As has been said, the primitive orders do not possess wings. But, in addition to these, there are higher types of insect which are secondarily wingless. That is to say, among the higher insects are groups which use their wings very seldom (e.g. crickets, earwigs); others in which the wings have become small and degenerate, so that they cannot function (some cockroaches, bed bugs) and still others that have lost all traces of them (lice, fleas). We can assign these wingless forms to the Pterygota because of their life history and other homologies with winged relatives. The wingless fleas, for example, go through the pupal rest which was originally used to allow development of functional wings.

The way in which wings arose is obscure. The number present seems to have soon become standardized at two pairs, which is the normal number found in the great majority of insect orders. In flying, the two pairs can beat together or alternately; probably the most efficient arrangement is for them to beat as one unit, for some of the better fliers have developed wing-coupling arrangements to ensure this. (The Lepidoptera and the Hymenoptera.) Many insects can fly well using only a single pair of wings. The Diptera (flies), for example, rely entirely upon the front pair; the hind pair have degenerated into minute rods. In other orders the hind pair only is used for flying, while the front one merely forms a cover for the delicate flying wings when at rest. This modification has gone to different lengths in various orders. In the Orthoptera, for example, both wings are laid backwards along the body when not in use. In this position, the forewings cover the hind pair and they are usually more leathery in texture. Though they still take part in flying, they are partly protective. This has been further developed in some of the Hemiptera where the forewings are more or less stiffened and opaque. Finally, in the Dermaptera and the Coleoptera, the forewings are solely protective and are useless in flight. In the former they are reduced to short, leathery scales and in the latter they are normally

stiff, horny covers ('*elytra*'), usually covering the entire abdomen and hiding the second pair when at rest.

Whereas wings that have been modified into mere protective covers are thickened and opaque, wings used for flying are very thin and usually nearly transparent. They are strengthened by hollow rods called the 'veins', and the pattern formed by these 'veins' is an important way of distinguishing insects. In the more primitive orders (e.g. *Orthoptera*), as in fossil insects, there are a number of main 'veins' running along the axis of the wing and connected by a network of subsidiaries. Later there was a tendency for reduction, leaving a few main 'veins' connected by straight cross-veins instead of a reticulation. This reduction has gone farthest in the higher orders leaving a comparatively simple pattern.

## (ii) *The legs*

Each of the three segments of the thorax bears a pair of legs. These legs have many more hinge joints than those of mammals, and it is only by very imprecise analogy that the various sections have been given corresponding names as follows:

- |                   |   |
|-------------------|---|
| (1) Coxa          | } Two short segments acting as pivots on the body |
| (2) Trochanter    |   |
| (3) Femur         | } Normally long segments                          |
| (4) Tibia         |   |
| (5) Tarsus        | (1-5 small segments forming a flexible 'ankle')   |
| (6) Pes (or foot) |   |

These names need not be memorized; but it may be of interest to know that the number of main joints in the insect leg is normally constant. The great differences between the stilt-like legs of crane-flies and the squat legs of lice are due to changes in proportion and shape.

The legs of most insects are used for normal walking or running and do not depart much from the primitive type. Insects which can jump or hop show one simple modification, usually of the last pair. The powerful jumping muscles result in one of the leg joints being much enlarged. Doubled under it (like a pair of nutcrackers), lies the next segment which applies the force when the two arms swing apart. In most of the jumping forms the enlarged joint is the femur, but in fleas the coxae are also enlarged.

In the parasitic lice, the legs are adapted for clinging to hairs. The arrangement for gripping is roughly similar to the pincers of lobsters and crabs.

There are a number of other interesting specializations, such as the flattened, oar-like legs of some aquatic insects, the digging legs of mole crickets and certain beetles and the pollen-baskets on the legs of hive bees. But none of these is characteristic of large groups.

The feet of insects generally consist of a pair of claws which are used for gripping slightly roughened surfaces. These tiny claws find foothold in such small irregularities as occur in unpolished wood and paper. In addition to the claws, there are often present two or three pads covered with minute glandular hairs. These are used for climbing on smooth polished surfaces and they are usually only present in

insects able to climb thus. This facility is curiously random in its distribution; some species possess it while quite close relatives are deficient. It should be noted that a film of dirt will often enable an insect (e.g. a bed bug) to climb a polished surface which it could not scale were it perfectly clean.

#### (d) Abdominal appendages

As has already been said, the ancestors of insects are believed to have had appendages on all the segments of the abdomen. These paired abdominal appendages of the primitive arthropod can be seen in the embryonic stages of most insects. But, except in primitive insects, where vestiges are retained even in the adult, most of them disappear before hatching. However, one or two pairs of these appendages on the last few segments of the abdomen are often retained by higher insects and modified for special purposes.

The appendages on the 8th, 9th (? and 10th) segments develop into external sexual organs used for copulation in the male and for egg-laying in the female. (The egg-laying appendages are termed the *ovipositor*.)

Among certain insects which live in large colonies (bees and wasps) there are females which have turned the ovipositor into a weapon, the sting.

On the 11th segment a pair of little tail-like appendages are sometimes retained as '*cerci*' which are usually sensory in function. Cerci may be either long and whip-like (bristletails, mayflies), or short (cockroaches) or reduced to a pair of forceps, as in earwigs.

### VI · CHARACTERISTICS OF INSECT LARVAE

Insects which undergo complete metamorphosis hatch from the egg (apparently at an earlier stage of embryonic development) as *larvae* which are quite different from the adult insects. This schism in the life history is due to specialization of their functions; the larva being concerned with feeding and growing, the adult with mating, migrating and reproducing. This differentiation has been carried to various lengths by different insects, according to the dependence of the larva on the provision made for it by its parents. In most of the higher insects, the parent lays eggs on or in an abundant food supply. When the eggs hatch, the larva merely has to browse on the food around it and accordingly has no need of well-developed limbs or sense organs, unlike less specialized forms which have to fend for themselves. Specialization, therefore, has resulted in degeneration similar to that found in parasitic forms.

It is possible to recognize different types of larva representing succeeding degrees of specialization. The distribution of the following types in the various orders is shown in Fig. 3.

#### (a) Primitive larva

This is the simplest, least specialized form of larva which leads an active, foraging life. The body is well armoured and legs and biting mouthparts are well developed. Small antennae and simple eyes (ocelli) are always present and a pair of cerci are

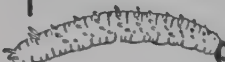

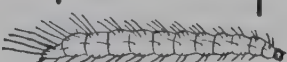

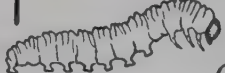




	Simple LARVA	CATERPILLAR	Legless GRUB	Headless MAGGOT
DIPTERA				
APHANIPTERA				
LEPIDOPTERA				
HYMENOPTERA				
COLEOPTERA				

FIG. 3. Diagram illustrating progressive specialization of insect larvae. (a) Carabidae; (b) Tenebrionidae (not exactly homologous with caterpillars); (c) Anobiidae; (d) Tenthredinidae; (e) Vespidae; (f) Tortricidae; (g) Pulicidae; (h) Bibionidae; (i) Muscidae. (After various authors.)

found at the tip of the abdomen. It will be observed that this type of larva does not differ much from the nymphs of simpler types of insect, the main differences being that the antennae are very short, while compound eyes and wing buds are never visible. Examples of primitive larvae are found in many families of Coleoptera.

(b) Caterpillar type

This is a more specialized form. It is hatched at a rather earlier stage of embryonic development when the segments of the thorax and abdomen are all very similar. Some of the evanescent abdominal appendages are retained as little round feet called 'prolegs'. On the other hand, cerci are never present. The integument is only weakly armoured, and the thoracic legs and antennae are reduced.

All these modifications suit caterpillars to a less active life and, indeed, none of them is predatory. Most of them live and feed on vegetation, while others occur in stored foodstuffs or clothing. Examples are found in the Lepidoptera and in the sawflies (a primitive family of the Hymenoptera).

(c) Grub type

There are certain larvae intermediate between caterpillars and maggots which can conveniently be described as grubs. The head capsule is always present and some

antennae and mouthparts can be discerned. The thoracic legs, however, are not functional or may be absent and 'prolegs' are never present. Many beetle grubs are fat and sluggish, lying on one side curled into the form of a C. On the other hand, the grubs of fleas and lower Diptera are active, though legless, progressing by vigorous wriggling movements.

(d) *Maggot type*

The final and most degenerate type of larva is the maggot. The head is very greatly reduced or apparently absent. Eyes or antennae are lacking and the mouthparts are very simple. The integument is soft, whitish and fleshy. Legs are absent and the whole body forms a simple cylinder, spindle or cone. They usually live inside or among their food, except in certain social forms where they are fed by adults.

Maggots are typical of the higher Diptera.

## VII · CHARACTERISTICS OF INSECT PUPAE

The pupal stage is a period of reorganization during which some of the larval tissues are broken down and the new adult organs are built. Naturally, it is rather a critical stage in the life of the insect. Very little movement is possible; usually only wriggling or flapping motions of the abdomen. (These are sufficient, however, for the jerky 'swimming' movements of mosquito pupae.) Being helpless, pupae usually require protection from enemies and from adverse physical conditions. Most insects therefore hide before pupating, sometimes forming themselves chambers in the earth or within the foodstuff in which they have been living. Very often a cocoon is spun from silk produced by the larva, the form varying from a smooth egg shape to an irregular tent spun against a corner. Miscellaneous fragments of rubbish are incorporated by some species to camouflage the little shelter.

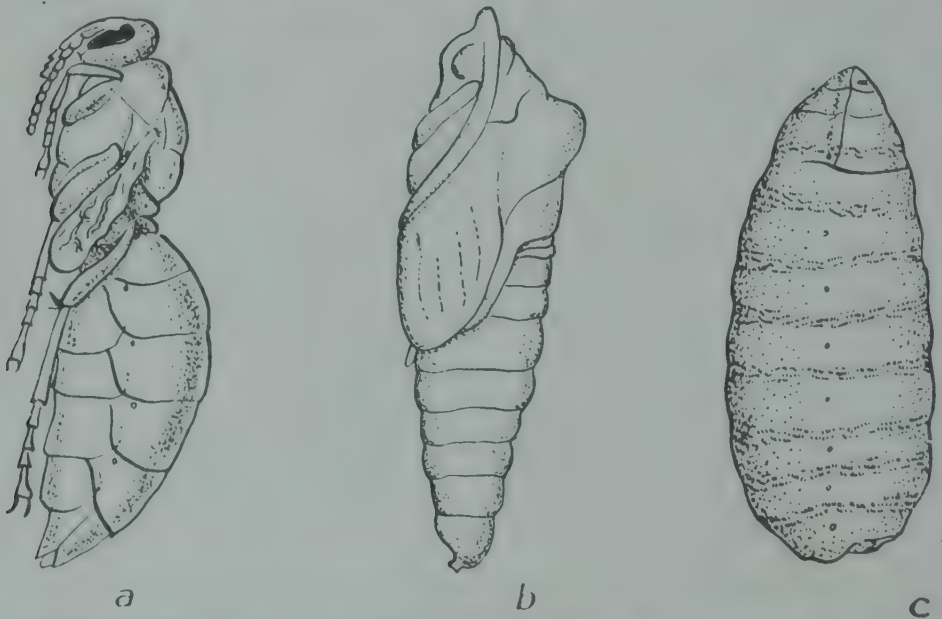


FIG. 4. Three types of insect pupae. (a) hornet, with limbs free; (b) moth with limbs fused to body; (c) advanced type of fly; pupa enclosed in last larval skin or puparium.

The higher Diptera usually dispense with cocoons and, instead, retain the cast skin of the last larval moult as a complete covering. This forms a smooth barrel-shaped envelope called the puparium. It becomes hard and dark brown in colour, and is often referred to as the pupa (though the true pupa is inside, of course).

In the outward form of a pupa it is possible to distinguish the new adult structures more or less clearly. The majority of pupae (including those of all the more primitive Endopterygota) have well-developed legs and wing buds. In order to accommodate them in the narrow pupal chamber, these appendages are held close to the body and directed backwards. This 'streamlined' effect is carried a stage further in most of the Lepidoptera by sealing the appendages to the body. (They are glued down by moulting fluid at the time of the last moult.) Thus there are two principal forms of pupae; free pupae with limbs separate and bound pupae with limbs glued to the body (see Fig. 4).

## VIII · CLASSIFICATION OF THE ARACHNIDA

From the figures on page 21 it is evident that the Arachnida are considerably less common than the insects. Moreover, they do not occur as pests to the same extent, almost all the troublesome kinds being mites or ticks of the order Acari. A very superficial sketch of the classification of arachnids will, therefore, be sufficient here.

Some nine orders of arachnids are generally recognized. The evolution within the group does not show any simple definite trends corresponding to the development of wings and of metamorphosis in the insect class. All that can be said is that the scorpions and certain minor orders are relatively primitive, the spiders are about the most highly organized and that the Acari are a degenerate group.

The characters on which the orders are distinguished are: the segmentation and arrangement of the body parts and the development of the mouthparts.

(a) *Segmentation*. In the scorpions and other apparently primitive orders at least a part of the body is distinctly segmented in the adult; in the spiders and Acari, however, all traces of segmentation are suppressed. In some forms the body is divided into two regions, sometimes separated by a narrow 'waist' or pedicel (as in spiders). In the Acari there is no trace of this division.

(b) *Mouthparts*. There are two pairs of oral appendages, either of which (but never both) may be large and important. In front of the mouth are a pair of '*chelicerae*' which are usually prehensile and behind it a pair of '*pedipalps*' the bases of which function as jaws. In some cases (scorpions) the pedipalps are claw-like.

The spiders and Acari can be distinguished from other orders of Arachnida by the following combinations of characters:

Both possess unsegmented bodies.

Araneae (spiders) possess	{	waist constriction (pedicel)
	{	large chelicerae
Acari (mites, etc.) possess	{	no pedicel
	{	large pedipalps

### 3. *Anatomy and physiology of insects*

#### I. THE CUTICLE

The body of an insect, like that of other arthropods, is covered all over with a cuticle, which varies a great deal in different insects, but is relatively much more firm and tough than the soft, pliable skin of most vertebrates. The primary function of this cuticle is, like skin, to act as an envelope; to retain body fluids and exclude foreign matter from the delicate internal membranes. But, in addition, it has acquired other important functions. Probably the first one was acquired in the remote ancestors of arthropods when hardened plates were developed in the cuticle to act as *armour*. This would be of some value in protecting an animal against enemies of the same order of size. But far more important than the protective function was the development of the cuticle into a jointed framework, by alternation of hard plates and elastic connective membranes; in other words, a *skeleton*.

The possession of a skeleton is essential for vigorous activity, especially to land animals. Two large and successful groups have evolved skeletons; the vertebrates with their internal skeleton of bones, and the arthropods which developed an external jointed cuticle. The adoption of an external skeleton had extremely important bearing on the subsequent evolution of arthropods in general and insects in particular. The reason for this is that, although the external skeleton possesses many advantages, it also involves inherent limitations which restrict the development of the group in certain directions. The two main advantages of the external skeleton are as follows:

(a) As already mentioned, the hard plates in the cuticle serve as protective armour (as well as a body support and framework of levers for locomotion). The internal bones of the vertebrates are only able to give limited protection in certain regions where they approach the surface (as the skull and ribs). Where additional armour has been developed in large animals, it has resulted in overweighing and is a defensive measure characteristic of degenerate groups approaching extinction.

(b) An external skeleton is mechanically much more efficient than an internal one. Thus, a hollow rod is much stronger than a solid rod of the same weight. Furthermore, a hollow skeleton provides a relatively greater surface for muscle attachments than a system of solid rods.

In contrast to these undisputed advantages, the great limitation of an external skeleton is the difficulty of growth within a non-living structure. This is met by the method of moulting, in which the old cuticle is discarded and a new, larger one secreted. During the interval between escape from the old cuticle and the hardening of the new one, an arthropod is without support. This is a very much more serious matter for a large animal than for a small one for the reason that the strength of a structure depends upon its area of cross-section, while the weight depends upon its volume. With an increase in size, the volume ( $x^3$ ) grows much more rapidly than

the cross-section area ( $x^2$ ), so that large objects require relatively stronger supports. In the interval of moulting, the soft living tissues have to support the whole weight of the body, and this restricts the size to which terrestrial arthropods can develop. (Aquatic arthropods can reach much larger size because their bodies are supported by the weight of water displaced.)

The limit of body weight which can be supported by soft tissues on land is about an ounce or two, and insects have never been able to exceed this size.

The small size enforced on insects by their external skeleton has a great number of interesting consequences which will be considered in subsequent sections, but one result which concerns the cuticle must be considered now. Animals of small size have a much greater surface area in proportion to their volume than large ones. This relatively large surface results in increased evaporation of water vapour from the body, so that small creatures like insects are in danger of desiccation if they live in dry environments. To guard against this, they have evolved complex water-proofed cuticles.

It is worth considering the main outlines of structure of the insect cuticle to understand the ways in which it is constructed to function as a skeleton and as a waterproof envelope. If a number of different kinds and stages of insects are examined under a hand lens, a great deal of variation will be found in the state of the cuticle. In some forms the cuticle is unusually thick and horny; in others the hardened plates are greatly reduced or even absent (as in fly maggots). But in the active adult stages, there will be found certain similarities in general disposition. The cuticular skeleton has to permit of two kinds of movement. First, there is the muscular movements of the body and limbs in the ordinary activities of life. The arrangements of hard plates to allow for these is reminiscent of a suit of armour or, by closer analogy, of the 'shell' of crabs or lobsters. Another type of movement is to allow for changes in the total volume of the body. This is particularly important for insects, many of which take relatively enormous meals. For example, a blood-sucking bug may gorge itself with several times its own weight of blood. To allow for these great expansions, the cuticular plates covering the abdomen are partly telescoped one inside the other and can contract or expand according to internal pressure.

The adaptation of the rigid cuticle to a permanent increase in size due to growth is made, as already mentioned, by moulting. This is carried out by swallowing air or water (according to environment) until the body swells beyond the capacity of the cuticle, which then bursts. The split occurs along a line of weakness, normally on the back of the thorax. The insect then gradually extracts itself, a difficult and hazardous procedure, since the cuticle extends up into various orifices derived from the skin (such as the foregut, rectum and tracheae or breathing tubes). Cast skins of insects are often found in infested places; in bug-infested houses, for example, they give evidence of a past or present bug population. Sometimes they are mistaken for the corpses of insects which have been eaten or sucked dry by other cannibalistic insects, or exploded by the miraculous powers of some insecticide!

After a moult, the new cuticle hardens on the extended skin and thus a larger volume is available for new growth. The proportionate increase in size at any moult

is often very constant for a particular insect. Each dimension increases about 20 to 50% which corresponds to an increase in volume of 100 to 200%.

The number of moults in an insect's life is small and constant in some species or it may be large and variable in others. Inadequate nutrition, causing a prolonged larval period, increases the total number of moults in many larvae. For example, the common clothes moth larva moults a minimum of four times before pupation if it is reared on a rich diet; but on a sparse diet, the development may be more than ten times as long and up to forty moults have been observed. Under such conditions, growth is very slow and the larva may even decrease in size after moulting! On the other hand, a bed bug passes through exactly five moults before becoming adult. If feeding is inadequate, the moulting is delayed.

The general form of the cuticular skeleton and moulting behaviour can be observed under a hand lens; but for more detailed information about the structure and properties of the cuticle, it is necessary to use microscopical technique and microchemical analysis. If vertical sections of an insect cuticle are examined under the microscope, it will be seen that it varies considerably in thickness. But neither of the characteristic properties of the cuticle – waterproofing and rigidity – are merely due to thickness; they depend on the chemical and physical natures of different layers.

The principal layers of the cuticle are as follows (see Fig. 5):

- (a) There is a relatively thick ( $100\ \mu$ ) colourless, elastic inner layer ('endocuticle').
- (b) In certain areas, corresponding to the hard plates of the cuticular skeleton, the outer part of this layer is altered (by a chemical process akin to the tanning of leather) to a stiffer, darker layer which is usually amber, brown or black ('exocuticle').
- (c) A thin ( $1\ \mu$ ) outer layer forms a continuous film of colourless, chemically resistant material ('epicuticle').

The two inner layers are often grouped together as the 'procuticle' and it is this layer which is responsible for the mechanical properties of the cuticle. Microscopic examination reveals a large number of fine ducts, known as 'pore canals', traversing the procuticle (Fig. 5); these are probably concerned with the transport of components of the epicuticle.

The epicuticle is generally concerned with waterproofing. It is covered with a very thin (about  $0.25\ \mu$ ) layer of wax. This wax seems to be similar to beeswax, but different insects have waxes with different melting points ( $30$ – $60^\circ\text{C}$ ). If this wax layer is removed by fat solvents or by abrasion, the insect begins to lose water rapidly and is in danger of desiccation. However, fresh wax will be secreted over small denuded areas if the insect is kept in a moist atmosphere. As a final complication, there is sometimes a very thin film of 'cement' present in some insects overlying the wax film and protecting it from fat solvents.

It may be wondered how these outer layers are secreted or renewed by the living epidermal cells, which are, of course, separated by a considerable thickness of non-living material from the surface of the cuticle. The answer consists in an enormous number of fine threads of living matter which penetrate the integument through the so-called 'pore-canals' (which are visible in microscopic preparations as fine vertical

lines). In addition, there are a smaller number of larger channels connecting cellular 'dermal glands' with the surface.

Microscopic methods have been used to study moulting. It was observed that the old cuticle becomes separated from the epidermal cells and a new cuticle is secreted (beginning with the outermost layer, the epicuticle). Then between the old and new cuticles, a small amount of fluid is secreted which gradually digests the old endocuticle, the material of which is reabsorbed by the insect.

The old exocuticle (where present) and the epicuticle are not attacked and these remain to be shed at the moult. This immunity of the epicuticle may explain why the new integument is not digested by the 'moulting fluid'.

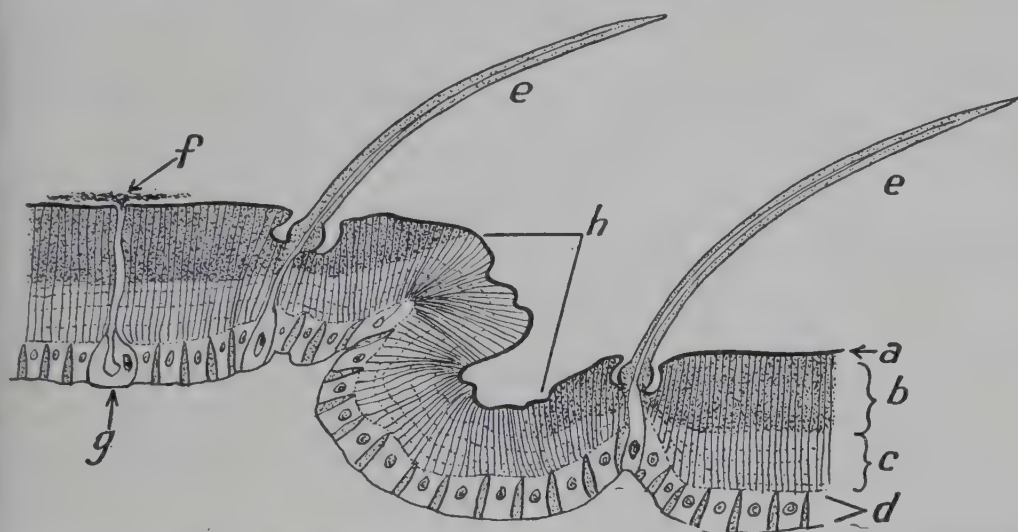


FIG. 5. *Diagrammatic cross-section through the cuticle of an insect (greatly magnified).* (a) epicuticle; (b) exocuticle; (c) endocuticle; (d) epidermal cells; (e) bristles or 'setae'; (f) cement, poured out by (g) gland cell; (h) intersegmental membrane. N.B. vertical lines through (b) and (c) are the pore-canals. (After Wigglesworth.)

Up to the time of moulting, the new cuticle remains soft and freely permeable to water. Shortly before moulting, the wax layer is secreted over the outside to render it waterproof; and after moulting, the chemical tanning process in certain areas lays down the hardened, darkened exocuticle plates.

### *Biochemistry of the cuticle*

The more important components of the cuticle are as follows. Chitin molecules resemble those of cellulose, both being long chains of glucose units linked together. In chitin, these units carry acetylamine groups. Chitin is tough, elastic and chemically stable.

The hard plates of the exocuticle are due to the presence of phenolic substances which are enzymatically oxidized to quinones in appropriate areas. These quinones link together adjacent protein chains, destroying some of their chemical activity and converting colourless soluble material into a horny brown, insoluble substance.

The thin epicuticle is formed of a lipoprotein on which is deposited a wax layer. The inner layers of wax molecules are tightly packed and orientated at right angles to the surface.

## II · MUSCULAR SYSTEM

The muscles of insects, like those of vertebrates, are of two main types: *skeletal* muscles, which are used for moving the limbs and the body framework, and *visceral* muscles, which surround the internal organs and are concerned with moving the food through the gut, and similar functions.

There is, however, less difference between the two kinds of muscles with regard to minute structure, since both are striated, whereas this is only true of the voluntary skeletal muscles of vertebrates.

There are often many more individual muscles in insects than in vertebrates; thus, some caterpillars contain up to 4000 (about ten times the number in the human body). To some extent this may be due to the greater surface area available for muscle attachments in a hollow skeleton. In vertebrates, groups of muscles are often combined to pull on a single tendon attached to one point.

### (a) **Skeletal muscles**

The skeletal muscles of insects are composed of spindle or strap-shaped bundles of fibres running from one point of attachment on the cuticle to another. Sometimes, at the points of attachment, processes of the cuticle are drawn inwards to form stronger anchors. Where there are many strong muscles acting, as in the thorax of many insects, there may be a number of ridges and arches of cuticle drawn inwards in this way forming a rudimentary internal framework (the 'endoskeleton').

The action of the skeletal muscles can be translated into movement in three principal ways:

- (i) Like vertebrate muscles, they can pull on the rigid parts of the skeleton across various joints, moving them as a system of levers. Also as in vertebrates, there are normally two muscles with opposing actions at each joint, one being for flexion and the other for extension. This arrangement is the usual method of moving the legs and other appendages.
- (ii) In some cases, the action of the muscles is to bend or distort a portion of the cuticle framework. The tension of the muscle here may be merely opposed by the elasticity of the cuticle or by another muscle tending to bend the cuticle in another direction. The principal example of this arrangement is in the wing muscles of most flying insects, which act indirectly on the wings by distorting the thoracic frame on which they are articulated.
- (iii) The contraction of certain groups of muscles may be balanced against hydraulic pressure of the insect's body fluids. This is quite a common mechanism in many soft-bodied larvae in which body movements can be brought about by appropriate contractions and relaxations of groups of muscles.

### (b) **Visceral muscles**

Visceral muscles either form irregular anastomosing sheaths round certain organs or, more usually, they run along or round the intestines. These muscles are responsible for peristaltic movements, which push the food gradually through the

gut. At certain points the circular muscles round the gut are enlarged to form thickened rings ('sphincters', as in vertebrates) which, by contracting or loosening, act as valves.

#### *Power and efficiency of insect muscles*

So far as experiments are able to show, the strength of insect muscles is not greatly different from those of vertebrates. The ability of insects to carry weights several times as heavy as their own bodies is referable to their small size on the lines mentioned in the previous section (see also p. 53). Since the power of a muscle is proportional to its area of cross-section and the weight of an animal is dependent on volume, small animals are relatively stronger than large ones, for geometrical reasons.

The speed of reaction of insect muscle to a stimulus is apparently of the same order as vertebrate muscle. There seem to be distinct differences in efficiency between muscles of sluggish larvae and vigorous adult insects. The speed of contraction and relaxation of wing muscles (which in some insects cause two to three hundred beats per second) is very remarkable.

#### *Biochemistry of insect muscles*

In its broad outline, the complex system of energy release in insect muscles appears to resemble that of vertebrates. The primary energy source is glycogen or glucose, which can be converted, with energy release, into pyruvic acid. Under anaerobic conditions, this is converted to lactic acid. Under normal aerobic conditions, the pyruvic acid enters into the Krebs cycle and is finally degraded into carbon dioxide.

### III · RESPIRATORY SYSTEM

The purpose of a respiratory system is to bring oxygen from the environment to muscles and other body tissues where it is needed to provide energy by oxidative processes. Vertebrates, being comparatively large animals with dense masses of tissue, cannot rely on simple diffusion to supply their oxygen needs; accordingly they have elaborated a secondary transport system, making use of the blood to take oxygen to all parts of the body. Insects are so small that they have nowhere great distances to transport the oxygen; consequently they can use a respiratory system simpler in principle than that of vertebrates. Indeed, a few very small and degenerate insects can manage without any respiratory organs at all, relying on direct access of oxygen to their tissues.

In the great majority of insects, however, air is brought directly to the tissues by a series of branching tubes, called '*tracheae*', which normally communicate with the air by pores known as '*spiracles*'. The tracheae are derived from invaginations of the cuticle and are lined with similar material. Usually they are strengthened by minute spiral thickenings which prevent their collapse under pressure. After branching repeatedly, the tracheae end in thread-like tubules which ramify among the tissues requiring oxygen.

Probably the primitive form of the respiratory system consisted of a pair of

spiracles, in every individual body segment, each leading to an independent bunch of tracheae. But, in modern insects, there are never more than two thoracic and eight abdominal spiracle pairs, and these numbers may be variously reduced. The extreme reduction is found in certain aquatic nymphs and larvae without any spiracles, the tracheal system being entirely closed, though full of air. In such cases the tracheae absorb oxygen from the water through the cuticle, usually in special gill-like areas.

The disposition of the tracheae has evolved in various ways. The independent systems in different segments have developed communications, especially in the form of a pair of longitudinal air trunks running right along the body, either laterally or dorsally. These main tracheae may conform to the usual circular (non-collapsible) pattern, or they may be oval in cross-section or expanded into large air sacs. Both these last-mentioned forms tend to collapse under pressure; their purpose will be described shortly.

### *Functioning of the respiratory system*

#### *(1) Simple diffusion*

It has been calculated that the normal oxygen requirements of most insects can be met by simple gaseous diffusion along the tracheae (assuming a slight concentration gradient due to oxygen depletion at the tissue end). Carbon dioxide produced as a waste product in respiration would likewise be able to diffuse outwards. But this gas can penetrate directly through body tissues much more easily than oxygen, and in many insects a substantial proportion of it escapes from the general body surface in this way.

An interesting arrangement regulates the supply of air to the tissues according to their fluctuating demands. The fine tubules at the end of the tracheae ('tracheoles') are largely filled with liquid while the insect is at rest. After muscular activity, certain chemical substances requiring oxidation tend to accumulate in the muscles and their presence sucks out the liquid by osmotic tension. Thus, the column of air is drawn down to the tissues requiring oxygen.

The readiness with which oxygen can diffuse into the respiratory system implies that water vapour from the insect can easily diffuse out. As already pointed out (p. 35) the water balance of an insect is rather precarious owing to its large surface-to-volume ratio. Therefore, this additional source of water loss would be dangerous and it is prevented in the great majority of insects by valves at the spiracles which can be kept closed most of the time, or opened when muscular exertion demands a period of free air diffusion. The stimulus which operates these spiracular valves is the presence of carbon dioxide, and it can be shown that insects kept in air with an unusually high concentration (say 5%) of it keep their spiracles permanently open.

#### *(2) Ventilation*

In many of the more active insects, the physical diffusion of air into the tracheae is supplemented by 'breathing' movements which serve to ventilate the main air trunks. These movements are carried out by the abdomen and there are two general methods: either the dorsal and ventral surfaces are alternately drawn together and

separated, or the various entire segments are extended and contracted with a telescoping movement. (Movements of this sort can be observed with ease in many active insects, such as wasps, bees and flies.) The effect of these respiratory movements is alternately to compress and expand the large tracheae, especially the collapsible sections, thereby ventilating the main trunks of the respiratory system.

In some insects there is evidence of directional ventilation produced by respiratory movements combined with opening and closing of appropriate spiracular valves. Thus, the air may be drawn into the thoracic spiracles and expelled from the abdominal ones, or vice versa. But these special adaptations are not general nor are they rigidly followed under all conditions by individual insects.

### (3) *Efficiency of insect respiration*

The oxygen requirements of insects are of the order of 1 milligram of oxygen per gram weight per hour; but this varies considerably in different species and according to circumstances. As already mentioned, the demand for oxygen increases very greatly after muscular exertion as it does in vertebrates. In addition, it is very much augmented by a rise in temperature like all other aspects of insect metabolism (see pp. 56-57).

Compared to vertebrates, the insects are extraordinarily resistant to asphyxia. They can revive after periods from one to eight days in the absence of oxygen. To some extent, this may be due to the comparative simplicity of their respiratory system. On return to air, the oxygen can diffuse directly to the tissues without the aid of any special transport system actuated by a complex nervous control.

### *Biochemistry of respiration*

Like other animals, insects derive their energy from oxidative processes in the tissues. These reactions are catalysed by a complex variety of respiratory enzymes. On the one hand, the hydrogen of the substrate (i.e. energizing nutrients) is activated by dehydrogenase; and on the other, the atmospheric oxygen is made available through various enzyme-carrier systems. One of the most important employs the carrier cytochrome (a mixture of three haemochromogen compounds) which is widely distributed in insect tissues, especially muscles. This substance alternately takes up and liberates oxygen under the influence of an oxidase enzyme. There are also other, less important, systems (e.g. employing glutathione as a carrier). The cytochrome system is paralysed by cyanide, but other systems are insensitive and are able to maintain respiration at a low level during cyanide poisoning. The final union of the oxygen and hydrogen produces the compound hydrogen peroxide. A special enzyme, catalase, is present to split this into oxygen and water and so prevent its accumulation in the tissues.

## IV · DIGESTIVE SYSTEM

Insects vary greatly in their feeding habits and different types subsist on such dissimilar things as green leaves, rotting organic matter, other insects, wood, wool and

mammalian blood. To cope with such diverse sources of food, the external mouthparts are radically modified in various ways, as already mentioned (p. 26). These elaborate mouthparts usually conceal the actual mouth of the insect, because, even in their simplest form, they lie folded over it. The more specialized mouthparts, such as those for piercing and sucking or those for licking up liquid food, are brought together to form a kind of proboscis, carrying a feeding tube leading to the mouth, which is completely hidden.

In addition to the mouthparts, there is usually present a lobe or fold projecting from below the mouth, at the base of which discharges a duct from a pair of salivary glands. The secretion of these glands cleans and moistens the mouthparts when they are not in use and, in addition, it often contains digestive enzymes which mix with the food when it is swallowed. In many bloodsucking forms (but not all) the salivary juice contains certain anticoagulants which prevent blocking of the narrow food-channels by clotting of blood.

The internal digestive system consists of the alimentary canal which, in its simplest form, is a tube running from mouth to anus. Usually it is elaborated in various ways; by lengthening and coiling, by expansions at various points and sometimes by pouches or other blind diversions. There are three fundamental divisions of the digestive canal corresponding to their embryological origin; the foregut, the midgut and the hindgut. The foregut and hindgut are derived from skin-forming tissue (ectoderm) and in the grown insect they still retain a thin coating of the cuticle which forms the external covering of the insect. This internal lining is shed with the rest of the cuticle at each moult.

In many cases the walls of the midgut are also separated from the food by a thin sheath-like membrane which is formed at the anterior end and covers the food like a continuous sausage skin. The purpose of these internal linings seems to be to protect the delicate tissues of the gut from abrasion by the continual passage of food. In vertebrates the soft intestinal walls are protected by lubrication with mucous secretion; but the self-cleaning and lubricating, ciliated 'mucous membrane' of vertebrates does not occur in the arthropods.

The foregut begins at the mouth and runs back through the head, in which region it often expands to form a sucking pump for imbibing liquid food. The usual form is a capsule, which can be dilated by muscles attached to the cuticular skeleton of the head and collapses from its own elasticity. From the head region the foregut runs back usually as far as the abdomen, where it enlarges to form a 'crop'. In its primitive form, the crop is merely an enlargement of part of the foregut which leads on to the next portion of the alimentary canal. But in some insects the crop is a blind sac and the communication with the midgut arises from the tube running back from the mouth.

At the junction between foregut and midgut there is a portion surrounded with powerful muscles which by contracting can act as a valve. Sometimes in this region there is a kind of gizzard provided with cuticular teeth which further triturate the food before it passes into the midgut. The surface area of the midgut is often enlarged by expansion into a sac-like form or elongation; it often fills a large part of the abdomen. At its posterior end is another muscular valve which regulates the

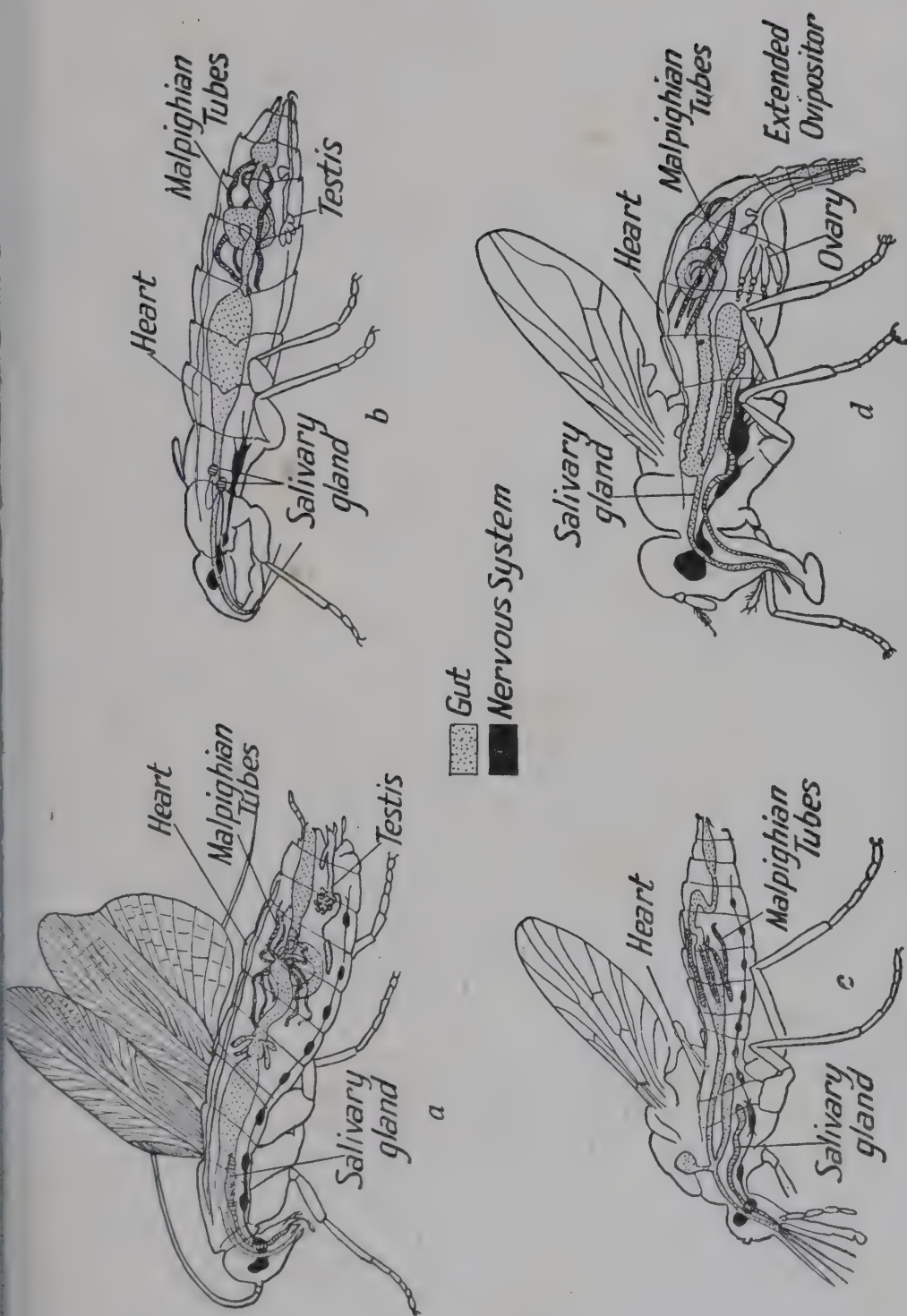


FIG. 6. Disposition of the internal organs in various insects. (a) cockroach; (b) bed bug; (c) mosquito; (d) housefly. (a, c and d) after Weber; (b) original.

passage of food into the hindgut. The hindgut finally communicates with the anus at the end of the body. From its anterior end diverge a number of fine tubes (the 'Malpighian tubules') which are excretory in function.

### *Functioning of the digestive system*

Broadly speaking, the main functions of the three principal divisions of the alimentary canal are as follows:

The foregut receives the food, the midgut digests it and the hindgut assembles the waste products for evacuation.

From the mouth, the food passes directly into the crop which acts as a temporary store and from which it can be gradually released into the midgut for digestion. This is often useful for sucking insects which take a very large quantity of food (blood, nectar, etc.) at a time. In some cases, however, the crop is absent and the food passes directly into the midgut. Partial digestion may occur in the crop owing to the presence of enzymes, either from the salivary juice or else passed forward from the midgut.

In the midgut, the food is attacked by appropriate digestive enzymes according to the type of insect and the food on which it lives. Thus omnivorous insects have enzymes to digest sugars, starches, fats and proteins; but carnivorous or coprophagous forms may be able to digest only proteins and fats. Often the type of food digested varies enormously at different stages of the life history, especially of insects with complete metamorphosis.

During the larval period there are usually many enzymes present to deal with different types of food necessary both for growth and providing energy. If larval or nymphal forms are insufficiently fed or are given an inadequate diet, they are often able to survive for long periods of time without growing; indeed, they may actually decrease in size. In many adult forms there is specialization on carbohydrate foods to obtain energy with a neglect of proteins. Sometimes the food reserves accumulated in larval life are quite sufficient for the adult which therefore takes no food at all (e.g. several moths). In the higher Diptera there is extreme specialization on protein digestion in the larvae, while carbohydrates are quite sufficient for the survival of the adults. The females, however, require proteins for maturation of the eggs.

The appropriate enzymes are secreted by the cells lining the midgut and these cells also absorb the degenerated food. Naturally, where there is a protective membrane present round the food, it is freely permeable to the enzymes and the food constituents which are absorbed. From the cells of the midgut the nutrient substances are removed by the blood and distributed round the body. Food may be stored in a rather diffuse organ, the *fat-body*, which is often present as a layer beneath the skin and sometimes in a layer round the gut.

In the hindgut the residues of the food are prepared for evacuation. Insects which live in a dry environment and especially if they live on dry food, need to conserve all the water they can. Accordingly, all possible water is extracted from the liquid mass received from the midgut and the faeces are discharged as comparatively dry pellets. In other insects, with a diet containing much water (plant sap,

blood, etc.), the faeces are always liquid and this is sometimes passed continuously in order to get rid of the excessive quantities of water (e.g. certain plant bugs).

The total time taken by food in passing through the alimentary canal varies in different insects (and with the temperature); observations have recorded periods of 2 to 3 hours in silkworms, 9 to 33 hours in a cockroach, and 2 to 4 days in the larvae of the clothes moth.

### *Biochemistry of digestion*

Insects digest the more ordinary food components by enzymes which appear to be similar, in general, to those of other animals. These include protease, lipase, amylase, invertase and maltase for dealing respectively with proteins, fats, starch, cane sugar and maltose. The various portions of the alimentary canal (crop, midgut, etc.) in which these enzymes are secreted are maintained at a suitable pH for their efficient functioning. As already mentioned (p. 44) a complete battery of enzymes is only possessed by omnivorous insects; those with specialized diets are restricted to appropriate enzymes.

In addition to the more ordinary food materials, some insects are able to digest rather refractory substances. Sometimes this is by virtue of symbiotic micro-organisms in the intestine (often in special pockets) which carry out part of the digestive processes for the insect. Thus the digestion of cellulose by termites and some wood-feeding beetles depends on this arrangement. There are, however, other wood-feeders which are able to digest cellulose by an enzyme, cellulase, which they secrete themselves. Among the more interesting digestive feats is the consumption of keratin by clothes moths and carpet beetles. Keratin consists of long peptide chains linked together side by side by S-S cross-linkages which protect them from normal proteolytic enzymes. There is apparently some reducing agent present in the midgut of these fabric pests which splits open these bonds and allows the residues to be attacked by a special proteinase which is unusually insensitive to the presence of —SH groups (see pp. 261–262).

## V · NERVOUS SYSTEM

The fine structure of the nervous system of insects has some points in common with that of vertebrates. It is composed of nerve cells which have characteristic long thread-like processes (axons) which transmit nervous impulses from one part of the body to another. The majority of these cells are concentrated in the central nervous system, which consists of a series of nerve masses or ganglia lying *ventrally* in successive segments and connected with a pair of nerve cords running longitudinally. At the front, in the head, these two cords diverge upwards, passing on each side of the foregut, and unite to form a large composite ganglion which serves as the brain. From this central nervous system bundles of axons run out to various areas of the body; these bundles are the nerves.

Nervous impulses are apparently of an electrical nature, for stimulation results in rapid alternations in potential (about 30 times per second) which travel along the

axons. The impulses in a group of axons tend to become synchronized and trains of such synchronized impulses come inwards to the central nervous system when the sense organs are stimulated. The branched ends of the axons are able to transmit the impulses to neighbouring nerve cells and the latter may thus pass in a complex path through the central nervous tissue. Finally, the impulses may be sent out along another type of nerve leading to a muscle or gland where it stimulates some form of response (contraction of the muscle, secretion of the gland, etc.). The incoming impulses travel along *sensory* nerves and the outgoing ones along *motor* nerves. This provides the anatomical basis for the simplest type of behaviour, the *reflex* action. This concerns only the local ganglion of the central nervous system and is independent of the brain. A certain stimulus is envisaged as producing a predictable effect by sending an impulse up sensory fibres, through a predetermined path in the ganglion, and emerging along the motor fibres to effect the response.

The brain of the insect receives important sense impressions from the eyes and antennae which modify the behaviour of the insect in various ways. It seems that the brain regulates the actions of the body principally by stimulating or by inhibiting the action of various reflexes. On the other hand, it is somewhat less important as a co-ordinating centre than the vertebrate brain, for most insects can walk and fly when decapitated.

### *Sense organs*

#### *(i) Eyes*

As already mentioned (p. 26) two kinds of visual organs are found in insects: the small simple eyes and the compound eyes, which are often large and prominent. The simple eyes, which are the only visual equipment of larvae, are somewhat variable in construction, but are never capable of very precise definition. Their usual function is to distinguish light and darkness and they are very sensitive to changes in illumination. When simple eyes are present in adult insects they occur on the top of the head. Their function seems to be to assist in accommodation of the compound eyes to changes in light intensity.

The compound eyes of adult insects and nymphs are complex organs capable of some visual acuity though apparently much inferior to the vertebrate eye and quite different in principle. Each facet of the compound eye contains its own lens and is, in fact, a separate optical system insulated by black pigment. Sometimes the light-sensitive elements receive impressions from several of these optical elements (nocturnal insects), but usually each element has its own light-perceiving cell. The effect is to assess the visual field by a mosaic of dark and light patches corresponding to the facet elements. The acuity of vision depends on the number of facets and the smallness of the angle they subtend. Experiments with bees (which have relatively keen sight, for insects) indicate that they can distinguish only gross differences in shape. On the other hand, insects can usually perceive movements very readily, and the efficiency of certain predaceous forms in seizing their prey proves that they are also able to judge distances to some extent. Visual powers vary very much according to the demands made on them by the habits of different types of insect.

*(ii) Tactile organs*

Owing to its cuticular covering, the insect's skin is not sensitive to contact. The sense of touch is therefore served by the bristles borne over most regions of the body. These are supplied with nerves which are stimulated if the hairs are bent or distorted.

*(iii) Hearing*

The finer varieties of tactile hairs have a general sensitivity to air vibrations, including audible sounds. Another type of organ of some complexity is found in a few species, particularly those in which one sex makes chirruping or other vibratory noises to attract the other. These special organs, which involve a sensitive cuticular drum, may occur in quite different parts of the body, such as the sides of the abdomen or the lower part of the front legs. The variability in their sound receptors suggests that the sense of hearing must vary greatly in different species, both in quality and acuity. Insects do not generally respond to miscellaneous sounds, but only to specific stimuli, such as sounds made by the opposite sex; but this may be a mental characteristic rather than defective auditory powers.

*(iv) Taste and smell*

The sense endings which perceive chemical stimuli are usually minute rod-like organs projecting from the cuticle, sometimes clustered together in pits. They may be distributed all over the body surface, but are usually much more common in certain areas specialized for perception of chemical sensations. Taste of dissolved substances is usually perceived by the mouth, mouthparts, palps or tips of the front legs. The sense of smell in insects is usually localized mainly in the antennae, though the palps may also bear olfactory organs.

*Functioning of the nervous system**Behaviour*

It is possible to analyse much of the behaviour of insects into a series of reflex actions, that is to say, into automatic responses to certain stimuli. Many actions are certainly not done as a reasonable reaction to circumstances. For example, insects stimulated in a certain way will clean their antennae. But if they are offered a bristle or the antennae of another insect after stimulation, they will clean those instead of their own. Some insects will attempt to clean their antennae after they have been amputated or even after they have been decapitated. But although insect behaviour is not informed with conscious appraisal of all circumstances, it is not rigidly automatic. Even the reflexes are not invariable; they may fail or vary after constant repetition, or if the normal response is prevented, the result may be accomplished in other ways (e.g. if two legs which characteristically perform walking, swimming or antenna-cleaning movements are amputated, another pair may deputize for them).

The more complex kinds of behaviour are regulated by the brain, which chiefly acts by augmenting or depressing the sensitivity of the reflexes according to impressions received from the sense organs. Many stimuli tend to excite reflex activity;

thus light is necessary for many diurnal insects to execute reflex flying movements. In the same way sensations perceived by the antennae maintain responsiveness and after they are removed an insect may become sluggish and indifferent. Tactile stimuli, on the other hand, usually have an inhibitory effect which explains why many insects tend to remain at rest in crevices with their bodies touching many points of contact. The sensation of contact of the feet with the ground is another inhibitor. If it is broken, flying insects immediately begin to flutter their wings; but the wing movements cease if the insect is given a small ball of wool to hold and thereby restore the sensation of the feet touching ground. Similarly, bugs or beetles turned over on their backs will struggle violently to regain their feet; but their struggles cease if they are given a small object to hold.

Types of behaviour which seem to be purposeful are the means by which insects travel to a suitable environment. But some insects are able to reach favourable conditions by entirely empirical behaviour. Their amount of restlessness increases as external conditions deteriorate, so that they remain in unfavourable places for the shortest times and tend to come to rest in agreeable situations. A rather more elaborate method of choice by trial and error is seen in those insects which wave their antennae from side to side as they advance and test the environment; on a small scale, like a blind man with a stick.

Apart from the method of trial and error, many insects are able to orientate themselves in regard to a distant objective, and either seek or avoid it. The simplest mechanism of orientation appears to depend on the relative degree of stimulation of the paired sense organs. These stimuli are transmitted to muscular effort on each side of the body, which determines the course pursued. Thus, several larvae which travel either towards or away from light (according to type), will move along a calculable resultant angle between two sources of illumination. A more complex type of orientation depends on the insect keeping an image of the environment in the same part of the receiving field of the eyes.

It should be emphasized that the number of reflexes which govern an insect's behaviour is often large and that they drive it to act in the best possible way under normal circumstances. Thus, leaf-feeding larvae are impelled to climb upwards and towards the light, while soil or dung feeders turn downwards and away from light, and so on. Often a number of associated reflexes are brought into play so that they produce chains of behaviour which exactly suit the biological requirements of the insect and give the impression of reasoned behaviour. These we can properly call instincts (a much-abused term). It is characteristic of instincts that they are inborn in all individuals of a species so that each one will react in the same way without learning from others. The insect must proceed along the chain from point to point in the proper order; the apparently logical sequence is entirely upset by outside interference.

Although insects rely very largely on instinctive and reflex behaviour, it is not quite true to say that they do not learn by experience. This faculty, which is usually poorly developed, is displayed mainly by higher insects such as bees and ants. A number of insects seem to have another type of memory; they show evidence of appreciation of time. Many of them show rhythmic changes in behaviour corres-

ponding to day and night and these changes may persist even when they are kept under conditions of constant temperature and illumination.

### *Intelligence and instinct*

This brief account indicates the somewhat mechanical nature of insect behaviour. It seems that the higher functioning of the brains of insects are affected (like many other aspects of their biology) by their small size. It is true that, over a very wide range, the size of animals' brains are roughly proportional to the body weight, and brain power or intelligence is a function of the ratio brain-to-body weight. But there is a lower limit due to the fact that nerve cells do not vary very greatly in size, so that very small brains are restricted in power by the number of cells they contain.

The particular characteristic of intelligence is that it must be plastic; this demands an enormous number of possible ramifications in the brain requiring many millions of cells. On the other hand, reflex and instinctive behaviour needs a much smaller number of relatively fixed nerve paths. Accordingly, insects have developed mental processes of this kind, as we have seen. Their instincts are often complex and always so excellently adapted to their way of life that they give a superficial appearance of considerable intelligence.

### *Biochemistry of the nervous system*

#### *Axonic conduction*

As mentioned earlier (p. 45) a basic nerve impulse consists of a wave of depolarization travelling along the nerve fibre. The following chemical explanation has been advanced. The resting nerve membrane is permeable to potassium ions but impermeable to sodium ions. Sodium is in excess outside the membrane (maintaining a positive charge) and potassium slightly in excess inside. Depolarization is due to a sudden, temporary change in the membrane, allowing the sodium ions to rush in, so that the outer charge falls to zero or generally becomes negative. Then potassium ions flow out to restore resting potential, the whole process happening in 1 or 2 thousandths of a second. Finally, sodium ions are 'pumped out' again in some unknown way.

#### *Synaptic conduction*

The branched ends of neurons, communicating with each other and forming relays and complex integration systems, are called synapses. Nerve impulses across these junctions are mediated chemically and in vertebrates an important mediator is acetylcholine. The nerve impulse causes release of this chemical, which stimulates the neighbouring neurons and almost at once the stimulating chemical is destroyed by an enzyme, acetylcholinesterase. The system can be poisoned by certain compounds (phosphorus esters, carbamates) which inactivate this enzyme.

Acetylcholine occurs extensively in insect nervous tissue; but, for various reasons, it is not absolutely certain that it is playing the same role as in vertebrates. Nevertheless, the insect nervous system can also be paralysed by anticholinesterase agents and many of these have been employed as insecticides (see pp. 105-107).

## VI · CIRCULATORY SYSTEM

The whole body cavity of an insect is bathed with a colourless or sometimes greenish-yellow blood. Though it is not enclosed in a ramifying network of blood vessels as in vertebrates, this blood is gradually circulated about the body. The chief circulating organ, the heart, lies immediately under the dorsal cuticle; it consists of a chain of contracting chambers bearing inward-directed valves. Blood seeps into the heart through these valves and is driven forwards along it, when the heart pulsates. This causes a current of blood to be directed from the front of the heart into the head region. On its return, the blood is to some extent guided into different parts of the body by membranes which form broad and sometimes ill-defined blood ducts. Circulation into inaccessible portions of the body (e.g. appendages and wings) is assisted by supplementary hearts, or small pulsating organs, at various points. The heart beat is regulated by the general needs of metabolism and is therefore accelerated by a rise in temperature or by muscular activity. Under certain conditions the direction of circulation, both in the heart and other parts of the body, may actually be reversed.

### *Function of the blood*

The insect's blood functions as a chemical transport system to convey food from the gut to various organs, to remove products of excretion and to convey hormones. It has also a very minor role in respiration. There are no oxygen-carrying cells comparable to the red blood cells of vertebrates and there is generally no indication of any respiratory pigment like haemoglobin.

Phagocytes are, however, present and carry out their usual function of absorbing and removing small particles of foreign matter and sometimes bacteria. They also play a part in wound-healing by collecting to form a plug which seals the injury.

### *Biochemistry of blood*

Insect blood contains a small percentage of proteins comparable with the amount in vertebrate plasma, and a somewhat smaller quantity of non-protein nitrogen, mainly in the form of amino acids. The concentration of the latter is very much higher than in vertebrate plasma and it is responsible for much of the osmotic pressure of the insect blood. Uric acid, fat, sugar and some unknown reducing agent are other organic constituents of the blood.

The inorganic salt content is lower than that of vertebrates, the osmotic pressure being maintained by the excess of amino acids. Sodium salts are largely replaced by potassium; and calcium and magnesium are notably higher than in mammals.

## VII · EXCRETORY SYSTEM

The function of excretion in insects is principally carried out by the Malpighian tubules already mentioned (p. 44). These are a group of fine tubes, varying in number from two to one hundred and fifty or more, which discharge into the intestine at the region of the junction between midgut and hindgut. They are usually long and unbranched and lie freely in the body cavity, disposed in loops (Fig. 6).

These tubules perform an excretory function by eliminating unwanted chemical substances which occur in excess in the insect's diet. In such insects as take plentiful water with their diet, the waste products are washed down with plenty of excreted water. But forms with a precarious water balance excrete a nearly dry urine into the hindgut.

### *Biochemistry of excretion*

The exact composition of insect urine depends on the food of each particular insect and the substances in it which occur in excess; of these nitrogenous matter is always present. Nitrogen is excreted as free ammonia by several kinds of fly maggots and in the form of ammonium salts in a number of other insects. The main excretory form is uric acid, however, urea being present in much smaller quantities.

## VIII · REPRODUCTIVE SYSTEM

In almost all insects, reproduction is bisexual; the sexes mate and the male implants spermatozoa which subsequently fertilize the eggs which the female lays.

The sexual organs of male insects consist of a pair of internal testes comprising a number of follicles in which the sperms are developed. These sperms, mixed with glandular secretion, are discharged down tubes which unite to form a Y-shaped duct leading to the ejaculatory organ, the penis. Sometimes the sperms are not simply injected in a fluid mass, but are transferred to the female in a tiny membranous sac which is secreted by the male.

The intromittant organ and its associated structures are usually of very considerable complexity and they interlock with the genitalia of the female. Usually the details differ in closely related species (which is useful for identification) and this may be a natural mechanism to prevent cross-mating. (The 'lock-and-key' theory.)

The behaviour associated with mating shows remarkable diversity in different insects. One sex is very often attracted to the other by some special stimulus, either by sight, hearing (chirruping of crickets, etc.) or very commonly by special scent glands (many Lepidoptera). The act of copulation is carried out in a variety of ways in different species and the duration of union may be a matter of seconds, minutes or hours.

The reproductive organs of the female are a pair of ovaries which usually consist of a bunch of carrot-shaped egg-producing tubes united at the broad bases. The egg-tubes (which vary in number from one to over two thousand in different species) contain ova in different stages of maturity. The two ovaries are united by a Y-shaped duct which leads to the genital orifice, sometimes at the end of a long egg-laying projection, the ovipositor.

The sperms received from the male are seldom merely received simply into the egg-duct. Very often there is a special pouch in the wall to receive the sperms and sometimes this is reached by a separate copulatory orifice. From this pouch, the sperms are transferred after mating to a sperm reservoir from which they are released, little by little, to fertilize the eggs, usually just before they are laid. A single copulation will therefore supply the female with sperms to fertilize a large number

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of eggs, whether (according to the habits of the insect) she lays them all in a single batch or at intervals over a long period. Very often the eggs are coated with a gelatinous gum as they are extruded, which afterwards hardens and glues them to the spot where they are laid.

*Functioning of the reproductive system*

The number of offspring produced by a single female varies greatly according to the needs of the particular species. There are highly specialized forms which produce very few progeny; for example, the tsetse fly and other viviparous Diptera which give birth to larvae already hatched and developed. At the other extreme are the queens of colonies of social insects (p. 64) which devote their entire time to egg-laying and produce enormous numbers of eggs. In between are the great majority of insects which produce one or two hundred viable eggs in the course of their adult life. The number of eggs produced very often depends on the nutrition of the females, many of which demand proteinaceous food for egg production. In other cases (e.g. the clothes moth) the female relies on reserves accumulated during her larval life. Some females will lay no eggs until they have been fertilized, but others lay numbers of infertile eggs. In certain species, virgin females are able to lay eggs which develop normally (parthenogenetic reproduction).

## 4 · *Ecology of insects*

The effects of many natural forces and conditions upon insects differ profoundly from their effects on large mammals, so that an insect's impression of the world must be quite unlike our own. It is proposed in this chapter to discuss some aspects of insect ecology; that is to say, the relations of insects with their environment. It is convenient to divide this type of study into: (1) relations of individual insects with mechanical and physical factors and (2) the interaction of populations of insects with their environment and with each other.

### *A · Ecology of individual insects*

Almost all the unusual features of the relations between an insect and natural conditions are due to the relatively small size of insects. Many of these points have been raised already in connection with insect physiology and their inter-relations are shown in Fig. 7. As shown in this scheme, there are two fundamental physiological factors which limit insects to a relatively small body size. These are: (a) their adoption of an external skeleton which demands a size compatible with self-supporting soft tissues during moulting (pp. 34-35) and (b) their tracheal respiration which, depending largely on diffusion, is only possible for an animal without a large volume relative to its surface (p. 40). Insects, therefore, are all rather small animals and this fact has affected their way of life in various ways, some favourable and others adverse.

#### I · CONSEQUENCES OF SMALL SIZE

##### (a) **Relative strength**

As already explained, the small body volume compared to area of cross-section renders insects relatively tough and strong. They can carry weights many times as heavy as themselves and jump distances very many times their own length. Relatively enormous forces are needed to crush them; thus, when a lousy man 'pops' a louse between his fingernails, the force exerted is about 500,000 times the weight of the offending insect.

##### (b) **Air resistance**

In a vacuum all bodies fall at the same speed; but in air they are slowed down, roughly according to the ratio of their weight to their area of outline. An insect falling in air soon reaches a maximum velocity which is quite slow. For this reason, combined with their relatively robust structure, they are quite unharmed by falling from any height. On the other hand, they are much more seriously affected by wind

than larger animals unless they are large or strong-flying insects. Samples taken from kites and aeroplanes have shown that for several hundred feet above the earth there are thousands of small weak insects drifting about in air currents, especially in summer months.

### (c) Surface forces

Among the natural forces important to insects because of their small size are the molecular film forces at interfaces. The surface tension 'film' on the top of water is strong enough to bear the weight of many insects and there are several species with specially waterproofed legs that spend their lives 'skating' about on the water surface of ponds. On the other hand, if an insect breaks the surface film, it is a matter of



FIG. 7. The relationships between insects and their environment. (Original.)

greater difficulty for it to escape (witness the struggles of a fly wetted with milk or beer). Most insects have fairly waterproof cuticles (p. 36) which usually protect them from being trapped in drops of water.

The small size of insects enables certain forms to take advantage of forces of adhesion between closely opposed solids by which they are able to walk up polished vertical surfaces.

### (d) Small brains

The limitation of the number of cells in the brain has, as already mentioned (p. 49), restricted the more complex kinds of behaviour in insects to the comparatively rigid patterns of instinct and precludes the more variable forms of intelligence.

### (e) Small bodies – short lives

Having smaller bodies, insects grow to maturity much more rapidly than larger animals. The usual life-span of an insect is about 6 months as compared with some 5 years for an average vertebrate. According to this ratio, insects pass through ten times as many generations in a given time and are subject to correspondingly more mutations. This probably accounts for the relatively precocious evolution of insects and other arthropods. By the time that the first mammals appeared, in the Mesozoic (some 150 million years ago), practically all the main types of modern insects seem to have been differentiated.

### (f) **Small environments**

As a result of their early and successful evolution, insects are by far the most numerous and varied class of animals in creation. But this great diversity would only be possible for a small terrestrial animal on a planet of this size, because, in a given area of the land surface of the earth, there are an enormous number of 'microclimates' differing from each other and from the general environment. These provide suitable biological niches to a host of small specialized animals. Thus a field, which is a comparatively uniform environment to a cow or even a rabbit, provides a large number of havens for different types of insects. (In the soil, under stones or rubbish, in and among various parts of different plants, in pools of water, and so forth.)

### (g) **Rapid loss of water**

The small size of insects implies a large surface/volume ratio, and this means a large area for evaporation of water vapour relative to their total volume. Insects vary considerably in the amount of water they can lose without harm, but eventually loss of water is always fatal. Conservation of vital water is therefore a serious problem for all small animals and restricts many of them to humid environments. There are many forms of insect which live in damp soil and similar situations, where the air is nearly saturated with water vapour. (Sometimes they live in a tiny protected microclimate, an oasis in an otherwise unfavourably dry environment.) Such forms are usually not protected against desiccation and if they are brought out into the dry air of an ordinary dwelling house room they soon die from loss of water. But the majority of insects spend at least part of their life in dry air and many of them live on very dry foods. They are protected from desiccation first by their special waxed waterproof cuticles. Secondly the escape of water vapour from the respiratory system is regulated by valves, as already described (p. 40). Thirdly, a great deal of water is extracted from the food when it is lying in the hindgut prior to evacuation (p. 44). And finally, in such forms as live in a dry environment on dry food (e.g. mealworms, etc.) the insect is able to retain water produced by oxidation of the food in the body in the ordinary process of metabolism.

The drying power of air depends not merely on its degree of saturation but also on its capacity; in short its desiccating powers are related to saturation deficiency rather than to relative humidity. The normal environment of domestic pests, the human dwelling house, is usually considerably drier than most natural environments, especially in winter when the temperature is kept above that of the outside air. Thus at an English winter temperature of  $7.5^{\circ}\text{C}$  ( $45^{\circ}\text{F}$ ) outdoors, a saturation deficiency of about 3 mm Hg might be expected; inside a house moderately heated to  $19^{\circ}\text{C}$  ( $65^{\circ}\text{F}$ ) the saturation deficiency will be increased to 10 mm Hg. The extent to which insects can infest dwelling houses, therefore, depends to some extent on their resistance to desiccation. Types which demand nearly saturated air can only exist in microclimates indoors (e.g. flea larvae under rubbish, blowfly maggots in meat, etc.). Other varieties can survive in the free air space but only in rather damp or unheated rooms (e.g. silverfish, earwigs, furniture mites). Most of the more successful and hence better-known domestic pests are fairly well adapted to a wide

range of humidity; but under very dry conditions they suffer an appreciable mortality. Among the insects most resistant to desiccation are some of the pests of stored products (e.g. mealworm) which thrive under dry conditions.

#### (h) **Rapid loss of heat**

All the processes of living organisms (metabolism, growth and reproduction) are regulated by temperature. Presumably this is a summation of its effect on the biochemical and biophysical processes involved, since temperature has a direct effect on the rate of chemical reactions and on many relevant physical processes. In the higher vertebrates, the temperature of the body is maintained constant at an optimum level, which is considerably above that of the environment under most temperate conditions. But it would be practically impossible for a very small animal like an insect to maintain a constant warm body temperature, on account of the disproportionate amount of energy required, to offset the great losses due to radiation from its relatively large surface.

Insects do sometimes utilize metabolic energy in a way which warms them above their surroundings but the temperature rise is seldom great and usually only transitory (e.g. the flying muscles of some insects only function efficiently when warm; before taking flight therefore, they generate heat in them by fluttering movements). Insects are also able to cool themselves to some extent by evaporation of water in a manner analogous to cooling by perspiration. But the loss of water involved is very serious, particularly for small insects, and none of them can employ this cooling method for very long.

In consequence of their disabilities in thermal regulation, the body temperature of insects is very largely determined by that of the environment which, therefore, has a profound effect on their biology. From this point of view, the temperature scale can be considered as three general regions, as follows; the upper and lower portions are temperatures unfavourable (or, in extremes, lethal) to insects; while over the intermediate range they are able to develop normally. The location of this normal or 'biological' range varies according to the climatic adaptation of each particular species; usually it lies between 5°C and 35°C (41° and 95°F).

## II · EFFECTS OF TEMPERATURE

### (a) **Effects on insects of moderate temperatures**

At the lowest point of the non-injurious temperature range, the insect exists in a state of torpor with all its vital processes reduced to a minimum. Under such conditions the insect does not feed, but its food reserves are only utilized at a very low rate. Consequently insects are able to survive starvation for much longer periods in a cool environment than in a warm one.

If the temperature is gradually raised, a point is reached where the insect becomes active and the activity increases with the rise in temperature together with such other functions as heart beat, respiration and general metabolism. Since the insect is, in fact, living at a faster rate under warm conditions, the various stages and the complete life cycle run their course more rapidly than at low temperatures.

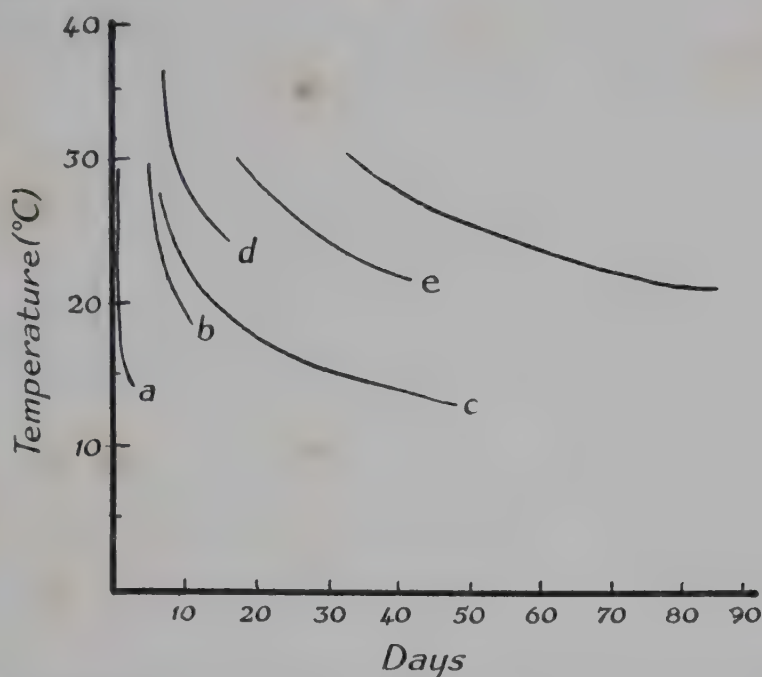


FIG. 8. Effect of temperature on the incubation period of insect eggs. (a) *Musca domestica* (house-fly); (b) *Tineola bisselliella* (clothes moth); (c) *Cimex lectularius* (bed bug); (d) *Pediculus humanus* (louse); (e) *Blattella germanica* and (f) *Blatta orientalis* (both cockroaches). (Data from various sources.)

This is illustrated by Fig. 8 which shows the average incubation periods, at different temperatures, of the eggs of various domestic pests.

The rates of growth and development are increased from two to five times by a rise of  $10^{\circ}\text{C}$  ( $18^{\circ}\text{F}$ ) in different species, the acceleration not being necessarily constant over the whole biological temperature range. A number of mathematical formulae have been proposed to express this effect of temperature but there is no simple law to cover all cases; this is hardly to be expected in view of the complexity of all the processes involved.

Since the rates of development and reproduction are so greatly increased by temperature, it is not surprising that proliferation of insects is very much augmented by warmth. This is the reason for the rapid multiplication of insects every summer in temperate climates and for their greater abundance in tropical and subtropical parts of the world.

An increase in temperature has a pronounced effect on water loss by insects. Owing to the greater drying powers of warmer air, the more rapid diffusion of water vapour and the increased activity of the insects necessitating opening of spiracular valves. Temperature, therefore, favours insects by accelerating their development but exercises a restraint by increasing water loss. There is usually an ill-defined region known as the *optimum temperature zone* where these two factors balance most favourably for proliferation of each particular insect.

### (b) Diapause

Insect development does not always respond to temperature in a simple and direct way. In some species, individuals may go into a state of arrested development,

which is determined by internal factors (hormones) and not a simple direct response to cold. This is known as 'diapause', in contrast to 'quiescence' which is used to describe the direct response. Diapause can be induced indirectly by the environment; e.g. by temperature prevailing in early life or even that of the mother. Other instigators may be poor food, dehydration or changing hours of daylight.

Certain species, or strains within a species, will not complete development without a diapause; or there may be several normal generations (e.g. in summer) followed by one in which diapause is more or less obligatory. Biologically, diapause is a means of surviving adverse conditions, notably winter cold, and exposure to cold is the surest way to 'break' it, so that normal development will follow return to warmth.

Diapause can occur at any stage of the life cycle. Examples of egg diapause are found in *Aedes* mosquitoes; these often require drying for a period followed by re-activation by water and reduced oxygen (see p. 192). Larval diapause can also occur in mosquitoes (e.g. *Anopheles plumbeus*, p. 197) and in several moths, such as *Hofmannophila* (p. 320), or by beetle larvae (e.g. *Trogoderma granarium*, p. 299). In the adult stage, diapause causes cessation of reproductive activity as in *Anopheles messeae* (see p. 197).

### (c) Effects on insects of adverse temperatures

As the temperature moves above or below the normal range, its influence on an insect becomes progressively more harmful. The effects in moderately abnormal zones are only apparent after fairly long periods and in these regions the water relations of the insect assume an increased importance. At more extreme temperatures, the amount of injury depends partly on the severity of the heat or cold and partly on (usually the logarithm of) the period of exposure.

#### (i) Low temperatures

Insects vary considerably in their resistance to cold. Most species, living out of doors, have to pass long periods in the winter at some stage in their life history at temperatures near the freezing point. These insects adapt themselves gradually to low temperature, apparently by eliminating much of the water in their bodies and preventing the freezing of the remainder by biophysical means. Insects adapted to warm climatic conditions are, however, unable to adapt themselves to cold and eventually die even at temperatures several degrees above zero. Among the British domestic pests there are many insects of this type, invaders from tropical regions living in the artificially warmed winter climates of dwelling houses and other buildings. Nevertheless, some insects which are adversely affected by prolonged cooling are able to endure short exposures to extreme cold (e.g. the bed bug and the body louse can survive exposures of several hours to  $-15^{\circ}\text{C}$  or  $5^{\circ}\text{F}$  (see Table 2)).

#### (ii) High temperatures

At temperatures above the normal range, the feverish activity of the insects induced by warmth (involves opening spiracles!) combined with the drying powers of warm air, increases the rate of water loss to a dangerous level which is often fatal after

TABLE 2    *Lethal exposure to low temperature*

Insect	Stage	Tempera- ture	Exposure	Remarks	Author
<i>Cimex</i>	Adult	—17°C — 2°C	2 hrs 10 days		Kemper 1936
<i>Pediculus</i>	Adult	—10°C —15°C	7½ hrs 2 hrs		Busvine 1944
	Egg	—10°C —15°C	24 hrs 10 hrs		
<i>Blatta</i>	Adult	— 5.5°C — 8°C	1 hr 10 hrs	(from 30°C) (from 15°C)	Mellanby 1939
<i>Tineola</i>	Egg	—15°C	1 day		Back & Cotton 1926
	Larva	—15°C	2 days		

Resistance of insects to low temperature: Data from: BACK & COTTON (1926) *Furniture Warehousemen* 6; BUSVINE (1944) *Bull. ent. Res.* 35, 115; MELLANBY (1939) *Proc. Roy. Soc. (B)* 127, 473; KEMPER (1936) *Z. Kleintier & Pelztier* 12, 107.

some hours. At even higher temperatures the insect falls into a heat stupor and the effects of the temperature itself are harmful in quite short exposures. The lethal effects of heat on some varieties of domestic pests are shown in Table 3; it will be observed that all of them are killed within five minutes at 55°C (131°F) and in less than an hour at 50°C (122°F). During a short exposure to high temperature, some insects, especially large ones, are appreciably cooled by the water evaporating from their bodies. Therefore, hot dry air is less dangerous to insects than hot damp air which precludes cooling by evaporation; however, the reverse is true at somewhat lower temperatures where the effect of prolonged drying is the lethal factor.

### III · INFLUENCE OF FOOD SUPPLY

The effects on insects of abundant and suitable food is fairly obvious; it accelerates their growth, development and reproduction. The 'suitability', of course, depends on the feeding habits of the particular insect, but it must include primary nutrients and often subsidiary ones (some vitamins have been found necessary to insects).

The tolerance of different insects to inadequate food and to complete starvation varies considerably, even among insects living on a similar diet. Thus, the normal food of both the bed bug and the body louse is human blood; but whereas the bug may survive without food for more than a year, the louse starves to death in about a week. On the whole, insects are more plastic than vertebrates in this respect. Many species display a remarkable power of existing for long periods (many times the normal life length) on the borders of starvation. Often they actually grow smaller

TABLE 3 *Lethal temperature with different exposures*

Insect	Stage	5 min	30 min	60 min	Author
<i>Pediculus</i>	Egg	53.5°C	50°C	—	Buxton 1940
	Adult	51.5°C	47°C	46°C	
<i>Cimex</i>	Egg	—	—	45°C	Mellanby 1935
	Adult	—	—	44°C	
<i>Sarcoptes</i>	Adult	—	47.5°C	—	1942
<i>Xenopsylla</i>	Adult	—	—	40.5°C	1932
	Larva	—	—	39.5°C	
<i>Tineola</i>	Larva	53°C	43.5°C	—	Back 1935

Lethal temperatures for various insects with different exposure times. Data from: BACK (1935) *U.S. Dept. Agric. Bull. No. 1353*; BUXTON (1940) *Brit. med. J. No. 4130*, p. 341; MELLANBY (1932) *J. exp. Biol.* **9**, 222; MELLANBY (1935) *Parasitol.* **27**, 111; MELLANBY *et. al* (1942) *Bull. ent. Res.* **33**, 267.

(see p. 44). If the quantity of food allows the insects to reach maturity, the resulting adult will be much smaller than an adult reared on a liberal diet.

The need for food is dependent on the rate of metabolism, which is regulated by the temperature. Therefore, as the temperature rises, insects tend to feed at more frequent intervals. Nevertheless, the rate of development is so much increased that the insect does not have time to build up a large body and the adults produced are usually smaller than those reared at cooler temperatures.

The resistance to starvation naturally declines with an increase in temperature. In addition, the amount of activity influences the need for food. For this reason, an insect survives longest without food if it is left undisturbed by light or by mechanical stimuli in a situation which induces inhibition of movement. Thus, bed bugs allowed to rest in small crevices or fleas given fur or wool to burrow into, will remain quiet and so survive much longer than if they are kept in a bare glass tube.

### *B · Ecology of insect populations*

By a population in this sense, is meant a relatively circumscribed, interbreeding community; the isolating factor being, as a rule, a localized source of food. Such populations originate with the invasion of a few insects, or at least one fertile female into a suitable breeding zone, which subsequently becomes colonized or 'infested'.

In addition to the influence of non-living environmental factors on the growth of populations, there are several ways in which the presence of the insects themselves affects the environment and each other.

## I · EFFECTS OF POPULATION DENSITY ON PROLIFERATION

### (a) **Low numbers**

The growth of very sparse populations is sometimes handicapped by the reduced chances of males finding a female with which to mate. This may, perhaps, be a reason why very small infestations sometimes die out without any special measures being directed against them. Many insects are somewhat gregarious which tends to keep the progeny of a single brood together in a limited area and thus reduces the likelihood of extinction from this cause.

### (b) **High numbers**

Insect reproduction is normally so prolific that feeding areas are very liable to become heavily populated and severe competition for food ensues. Where the competition is merely between individuals of the same species, the result is that some of the weaker ones die before reaching maturity; another effect is the stunting of the survivors owing to inadequate food. If there are two or more species with similar food habits, usually one gains the upper hand and others may become extinct. Thus if *Musca* and *Phormia* maggots compete for development on a small piece of meat, the latter are less adapted to overcrowding and are often exterminated. Similarly, with beetle pests of stored farinaceous food, the genera *Trogoderma*, *Gnathocerus* and *Tribolium* tend to die out in that order, because the *Tribolium* is most resistant to competition.

As the density of a population increases, it becomes more vulnerable to natural enemies. Among insects (as among other animals) there are parasitic and predatory species, the former being, perhaps, rather more important. In addition there are mites, fungi and bacteria which attack insects, particularly under rather humid conditions. Parasites and predators can only flourish with a relatively large population of their host or prey (which stands in relation to them as a food supply). The depredations of these natural enemies exercise an important check on the excessive growth of populations of many insects. Domestic pest insects are, indeed, attacked by singularly few insect enemies. On the other hand, they are very subject to attacks by man which, like those of the parasites and predators, are most active against large populations. Apart from organized scientific control measures, the primitive methods of destroying insects are usually resorted to in proportion to the annoyance caused by the pest.

## II · DEDUCTION OF POPULATION TRENDS UNDER NATURAL CONDITIONS

The previous sections have dealt with some of the ways in which various environmental factors influence the biology and population growth of insects. These facts were learnt from laboratory experiments in which it is possible to rear insects under any desired combination of conditions. Theoretically it should be possible, after sufficient study of the relevant variables, to predict the trends of population growth

in nature. The following data must be obtained for various combinations of food supply, temperature and humidity: length of life of the female, her chances of being fertilized, the number of eggs laid per female per day and the duration of, and mortality during, incubation and other stages of development. Even with all this information, the calculation of trends under natural conditions is complicated by fluctuating climatic conditions. Furthermore, there are some important factors, such as interference by man, which are often very hard to estimate quantitatively.

To compare the predicted population changes with actual events, it is necessary to assess the natural populations from time to time. This can be done by appropriate samples, the reliability of which can be determined statistically from their consistency. The measure of agreement between populations predicted from the prevailing conditions and estimated from samples, is an indication of the precision of our knowledge of an insect's biology in nature. Needless to say, such studies involve much hard work; but they are valuable in showing up the most important checks to population growth of particular insects and giving a proper perspective to systematic control measures.

An impression of the lack of knowledge of natural limits to population growth is given by certain calculations of the reproductive potentialities of a pair of houseflies in a single season 'provided that all their progeny survived'. These estimates range from 5000 million to 191 million billion. These calculations are, however, exercises in arithmetic rather than biology. A short consideration of some sober calculations of the bionomics of certain domestic pests may illustrate the different kinds of predominant influence which may curtail population growth.

(a) **The body louse** (*Pediculus humanus*)

(See Buxton, P. A. (1947) *The Louse*, E. Arnold, London)

**The itch mite** (*Sarcoptes scabiei*)

(See Mellanby, K. (1944) *Parasitol.* 35, 197)

These two human parasites are bracketed together because they live in environments with certain characteristics in common. From their proximity to the human body, both of them live at a nearly constant temperature and they are not normally subjected to adverse conditions of humidity. Neither species is subject to attacks by arthropod parasites or predators.

The body louse can be easily reared in captivity and the various bionomic characteristics (length of life, egg mortality, etc., etc.) can be estimated under conditions not greatly differing from natural ones. The probable population growth can be estimated within limits corresponding to maxima and minima observed in captive specimens. It is estimated that the progeny of a single pair would reach quite large numbers, in three months, if allowed to proliferate unchecked on an infested man (400-500 as a lower estimate; 4000 to 5000 as a maximum). Compared with observations on naturally infested people, these figures are both very high. The great majority of chronically lousy individuals carry a population of 10-20 lice; a few have hundreds of lice, but thousands are exceedingly rare.

In view of the absence of other checks to population growth, this fact must be

ascribed to louse killing operations of the infested people which are apparently conducted at intervals as the irritation from the lice reaches intolerable limits.

The scabies mite provides an interesting parallel case. For the first month after infestation, the host feels nothing; but thereafter a strong irritation develops, accompanied by erythema and vesicles. This reaction, which increases up to three months, has a drastic effect on reducing the mite population. (Many mites are scratched out of the skin by the finger nails, for example.) After the sensitivity to the mite has been fully developed it remains indefinitely, even if the infestation is cured. Consequently the skin reaction develops at once in a re-infested person (i.e. without a month's lag) and the combined effect of scratching and the unfavourable skin condition prevents a high mite population ever developing in secondary cases.

(b) **The bed bug** (*Cimex lectularius*)

(See Johnson, C. G. (1941) *J. Hyg.* **41**, 347)

There have been many laboratory studies of the quantitative biology of bed bugs, but until comparatively recent years, many of them were done at artificial temperatures much higher than normal winter temperatures in British houses. Using all the data now available, some calculations of population growth were made on the basis of thermographic records from sample rooms in London. The probable course of events in a regularly heated room (e.g. bed-sitting room or steam-heated flat) was found to be entirely different from an unheated bedroom. In the first case, breeding and increase of population continue from the summer throughout the winter months. But in unheated rooms, (i.e. most bedrooms!) where the temperature falls below 10°C for long periods, there is a pronounced adverse effect on the bugs which cease feeding and egg-laying and suffer a considerable mortality among eggs and young nymphs. This period of low temperature is calculated to cause a decided check on population growth and to reverse much of the increase to be expected during the summer.

Unfortunately there are practical difficulties in keeping an actual bug-infested bedroom under close observation over a long period. Where samples of bugs have been taken from natural populations, however, the proportions of different stages agree well with deductions made on the same data as the foregoing discussion. It is, of course, unnecessary to stress the great importance of warmth in favouring bug proliferation. (Any visitor to the tropics will confirm this.) The most interesting point of these investigations is the severity of the check to population growth caused by prolonged, moderately cool temperatures.

Where bug populations do grow to noticeable proportions they suffer from human attention; thus, ordinary cleansing operations will act as a check by killing eggs and sometimes other stages of bugs.

(c) **Stored product pests**

*Tribolium confusum* (see Park, T., Gregg, E. V. and Lutherman, C. Z. (1941) *Physiol. Zool.* **14**, 395 and elsewhere)

*Ephestia elutella* (see Richards, O. W. and Waloff, N. (1946) *Trans. R. ent. Soc.* **97**, 253)

Infestation of stored foodstuffs in dwelling houses commonly occurs in quite small amounts of food such as the contents of a tin or package. Assuming that the infestation is unnoticed and not interfered with, the populations of insects present will increase until they are limited by competition for the remaining food. The competition may be within a single species; or, in addition, between different species, as mentioned on p. 61.

Infestations of bulk food supplies (e.g. in a warehouse) may be affected by other factors before inadequate food becomes a serious impediment. Temperature will be highly important and sometimes natural enemies. Thus the warehouse moth (*Ephestia elutella*) is subject in the larval stage to a very high mortality caused by a wilting disease of fungal or bacterial origin. About 90% of the larvae died from this cause in the infestation which was kept under observation for many months.

### III · SOCIAL ORGANIZATION

Two of the characteristic qualities of human civilization are the use of tools and social organization. There are certain groups of insects which display apparently similar abilities in that they are able to excavate galleries in earth, plant tissues or wood and to make communal dwellings of earth, leaves, paper or wax, sometimes of considerable complexity. The social forms have a more or less elaborate caste system with specialization of the different types for fighting or for various tasks. Some kinds retain other insects in the colony virtually in the position of slaves and others tend as 'domestic animals' quite different species.

Insect societies have been developed at least twice in the evolution of insects; in the termites or white ants (which do not occur in Britain) and in the Hymenoptera (ants, bees and wasps). All of them are built up on the basis of two principal castes; sexual forms, specializing in reproduction, and sterile forms adapted to various other tasks. Owing to the plasticity of insects' bodies, it is possible for the reproductive requirements of a large colony to be met by only one or a few females known as queens. The bodies of some queen termites swell to a relatively enormous size, completely dwarfing all the other individuals; they become mere egg-laying factories.

The males in insect societies are comparatively unimportant. In the social Hymenoptera their function is to compete for the favour of fertilizing the queen, after which their task in life is done; the fate of drones in a beehive is well known.

All the miscellaneous tasks of feeding and protecting the colony and tending the young brood are done by the worker caste which is composed of sterile females. Often (ants and termites) their bodies are much modified to suit them for particular jobs; thus, the fighting workers, or soldiers, are provided with large heads bearing huge jaws, and so forth.

The complexities of behaviour in insect societies often reach remarkable heights and deserve a fuller study than can be afforded here. Nevertheless, it is fairly clear that these interesting feats are directed by a set of suitable complicated instincts rather than by an intelligence resembling that of the human mind.

Naturally, the bionomics of populations of social insects are more complex than those of simpler forms. The unit is not the male-female pair, but the colony, which

goes through various phases associated with the seasons. New colonies are formed by migration of excess sexual forms, usually produced in large numbers which depart all together in nuptial flights. Afterwards the fertilized females start work to commence new colonies by themselves (except in termites, where the male remains with the queen). In the colonies of some forms, only one queen is tolerated; but in others, several or many can exist. At later stages the queen usually becomes more and more dependent on the workers and, without an adequate retinue, they may starve. On the whole, however, colonies can tolerate an enormous mortality of the sterile workers without extermination.

## 5 · Organization of preventive and control measures

The prevention and control of domestic insect pests may be the concern of several kinds of people. In the first place, architects and builders are able to assist by giving thought to the liability of infestation of different types of construction. Secondly, the ordinary citizens resident in dwelling houses and other buildings are involved as the main sufferers, and also because the development of many infestations depends very much on the thoroughness with which domestic hygiene is pursued. Furthermore, the likelihood of a request for expert assistance in case of need depends on the proper outlook of the ordinary householder. To disseminate information about pests and the right way of destroying them, hygiene propaganda is useful; various official and unofficial bodies can help here. Thirdly, the Medical Officers of Health and the Health Inspectors of local authority Health Departments are involved in more serious infestations in their general duty of safeguarding public health. Some of their functions in this respect are legally defined. Lastly, commercial firms are interested in marketing insecticides and sometimes in providing labour to apply them. These various implications of domestic pest infestation are dealt with in this chapter under the following headings:

1. Building construction and pest infestation
2. Hygiene propaganda relating to insect pests
3. Sources of special technical information
4. Pest infestations involving local authorities
5. Commercial aspects of pest control

### I · BUILDING CONSTRUCTION AND PEST INFESTATION

For many years it has been recognized that insect infestation in buildings is favoured by certain constructional features and commonly occurring faults. The insects take advantage of different types of hiding place, from tiny crevices to large hollow spaces. The benefits of these hiding places to the insect should be clearly understood; they are twofold: (a) the concealment allows quite large populations of insects to develop unnoticed and renders them difficult to find; (b) the protection afforded prevents or reduces extermination by cleansing operations or by insecticides. Consequently, infestations are more likely to occur and persist in buildings with ample harbourage than in those providing little or no shelter.

#### *Prevention of harbourage for bed bugs*

Bed bugs will lodge in very narrow crevices (a millimetre or two wide) and many small bugs can be accommodated in a single nail hole. Apart from crevices in

furniture, bugs will infest cracks in plaster or woodwork, e.g. badly fitting joints round door or window frames, skirting boards or picture rails. Except with very careful workmanship, it is difficult to avoid this type of crevice developing in houses of conventional type; owing to warping or shrinkage of materials as they dry out and sometimes to settlement after building is complete. Details of building design, intended to assist in the prevention of bug infestation of new houses, are given in Section VI of the Medical Research Council Report on the Bed Bug (1942) and also in Chapter X of Functional Requirements of Buildings, British Standards Code of Practice III (1950). The importance of eliminating harbourages for bed bugs was considerably reduced, however, with the introduction of DDT and other residual insecticides, which have substantially reduced infestation in Britain and similar temperate countries. This does not mean that the matter should be entirely neglected, for it is still important, so far as possible, to prevent bugs hiding from the cleaning operations of the housewife and the torch of the Health Inspector.

#### *Prevention of harbourage for cockroaches*

Cockroaches still infest kitchens of old-fashioned houses, but they are much more common and widespread in permanently warm buildings such as centrally heated institutions and bakeries. In particular, the species *Blattella germanica*, which appears to be the most frequent offender at present, is a lover of warmth and is usually to be found in crevices near hot-water pipes. Cockroaches are large and active insects and there are records of their travelling quite long distances inside buildings.

For these reasons, the principal structures inhabited by cockroaches are pipe runs, ducts and chases. They are also troublesome in hollow wall spaces adjacent to ovens or kitchen stoves. On the whole, they are more difficult to eliminate with DDT than are bed bugs so that it is especially important to deny them access to deep and inaccessible harbourages. The spaces surrounding pipes passing through walls should be properly flanged and solidly packed with steel or glass wool. Intermediate lengths of ducts and chases should be capable of opening easily for inspection. Fibreboard partitions and similar constructions in kitchens should be carefully sealed with strips of gummed tape.

#### *Houseflies and blowflies*

The prevalence of flies and blowflies is not related to building design, except where it is proposed to fix screens to the windows of such rooms as kitchens, larders, canteens or lavatories (see p. 79). In that case, the windows must be designed to give adequate illumination from the unscreened fixed portions, while the ventilating sections must be made to open inwards.

Liability to a fly nuisance is, of course, affected by the location of a building. The breeding of flies is especially prevalent in certain places, e.g. refuse dumps, stable yards, slaughter houses, etc. Buildings, particularly dwelling houses, should not be sited near such places.

*Other insects*

Certain pests (e.g. silverfish, booklice, earwigs, furniture mites, woodlice) are favoured by damp conditions and the best defences against them are warmth and good ventilation. Of the pests mentioned, the earwigs and woodlice are invaders from the garden and are most likely to enter windows surrounded by creeper or bushes. Silverfish have a preference for starchy substances and may therefore attack wallpaper and other pasted or gummed materials. Booklice which exist on fungi or moulds, may be found in new buildings but these will disappear when brickwork and plaster have thoroughly dried out.

## II · HYGIENE PROPAGANDA RELATING TO INSECT PESTS

There is very little doubt that the prevention of many insect pests in houses in Britain depends largely on the standards of hygiene of the occupants. To some extent these have been moulded by upbringing and education (or lack of it) and resistance to improvement may be augmented by obstructive prejudices about insect pests. At the lowest level, one sometimes encounters archaic ideas in which the pullulation of parasites is associated with bodily vigour. More frequently there is evidence of belief in spontaneous generation. Finally, at a slightly higher level, there is often a false sense of shame which prevents the sufferer obtaining expert advice and treatment.

In its simplest form, therefore, hygiene propaganda should seek to combat prejudice and ignorance by dissemination of the simple facts of insect pest biology and of the best control measures. This may be done by use of leaflets, posters and articles, by exhibitions and by instructional films.

### (i) *Leaflets, posters and articles*

Leaflets and posters of a type suitable for children and the simpler members of the public may be purchased from the Central Council for Health Education, Tavistock House, Tavistock Square, London, W.C.1. Several of these concern flies and other household insects.

The magazine *Family Doctor* (published by the British Medical Association) contains articles on insect pests of hygiene from time to time.

### (ii) *Exhibitions*

A modern method of interesting and instructing the public about various pests and the best ways of exterminating them is by arranging suitable exhibitions. Progressive Health Departments may find it desirable to plan such exhibitions in conjunction with campaigns of rehousing. Living specimens and other material as well as advice can often be obtained from the biology department of a local university or technical college.

### (iii) *Films*

In addition to printed matter, the film is now taking its part in hygiene propaganda and education. The following films are available (in 16 mm or 35 mm, sound) from

various sources. They may be hired for moderate charges and some may be supplied free to educational establishments.

*Available from Central Film Library*

(Government Bld., Bromyard Avenue, London, W.3)

1. 'Fly about the house'. 1 reel: 9 min.
2. 'Scabies'. 3 reels: 26 min.
3. 'The scabies mite'. 1 reel: 7 min.
4. 'The story of DDT'. 2 reels: 23 min.
5. 'Unwanted guests' (head lice). 1 reel: 9 min.

N.B. Nos. 2 and 3 are only suitable for specialist audiences.

*Available from Rank Film Library*

(1 Aintree Road, Perivale, Greenford, Middlesex)

1. 'The blowfly'. 2 reels: 17 min.
2. 'The housefly'. 1½ reels: 16 min.
3. 'The intruders' (cockroaches). 2 reels: 15 min.
4. 'The mosquito'. 1 reel: 11 min.

*Available from Petroleum Films Bureau*

(4 Brook Street, London, W.1)

1. 'The Rival World'. Colour: 26 min.
2. 'Unseen Enemies'. Colour: 32 min.
3. 'Malaria'. 18 min.

### III · SOURCES OF SPECIAL TECHNICAL INFORMATION

#### (a) **Publications**

Various official bodies publish summaries of information in booklets devoted to the biology and control of various insect pests or to insecticides. Most of these can be purchased from Her Majesty's Stationery Office.

##### (i) *Published by the British Museum (Natural History)*

Also available at the Museum in Cromwell Road, London, S.W.7.

##### *Economic Series Booklets (prices about 1s. to 6s.)*

No. 1, The Housefly; No. 2a, Lice; No. 3a, Fleas; No. 4, Mosquitoes and their relation to disease; No. 4a, British mosquitoes and their control; No. 5, The bed bug; No. 11a, Domestic wood-boring beetles; No. 12, The cockroach; No. 14, Clothes moths and house moths; No. 15, Common insect pests of stored food products; No. 17, Some British mites of economic importance.

*Economic Leaflets* (prices 1d. to 3d.)

No. 3, The silver fish and firebrat; No. 4, Psocids; No. 5, Crickets; No. 6, Plaster beetles; No. 8, Carpet beetles; No. 9, Ants.

(ii) *Published by the Ministry of Agriculture, Fisheries and Food*

*Advisory Leaflets* (price 3d.)

No. 365, Houseflies, blowflies and cluster flies; No. 366, Ants in the house; No. 373, Insects infesting bacon and hams; No. 451, Wasps; No. 383, Cockroaches. *Technical Bulletin* No. 6, Common names of British insect and other pests (price 7s. 6d.).

(iii) *Published by the Department of Agriculture for Scotland*

*Miscellaneous Publication* No. 7, The biology and control of the ant pest (*Mono-morium pharaonis*) (price 1s.).

(iv) *Published by the Forest Products Research Laboratory*

*Leaflets* (prices about 1s. 3d.). No. 3, *Lyctus* powder-post beetles; No. 4, The death watch beetle; No. 8, The common furniture beetle; No. 14, The house longhorn beetle. *Bulletin* No. 19, Beetles injurious to timber and furniture.

(v) *Published by the Ministry of Health*

*Memo.* 238/Med. Memorandum on measures for the control of mosquito nuisances in Great Britain (price 2s. 6d.).

(vi) *Published by British Standards Institution*

(Available from British Standards Institution, 2 Park Street, London, W.1)  
*British Standard* 1831. Recommended common names for pesticides (price 15s.).

(vii) *Published by the World Health Organization*

*Reports of the Expert Committee on Insecticides*, e.g. 13th Rpt in *Techn. Rpt Series* No. 265: Insecticide resistance and vector control.

## (b) Reference centres

Information and advice concerning insect pests are available from various experts, free of charge in most cases, to *bona fide* inquirers.

(i) *The British Museum (Natural History)* (Cromwell Road, London, S.W.7) will usually undertake identification of specimens of pest insects.

(ii) *The Public Health Laboratory Service Reference Laboratory for Entomology* (London School of Hygiene and Tropical Medicine, Keppel Street, Gower Street, London, W.C.1) is comparable to other reference centres of the P.H.L.S. and provides specialist information on insect pests of public health importance.

(iii) *The Ministry of Agriculture, Fisheries and Food, Infestation Control Division* (Hook Rise, Tolworth, Surbiton, Surrey) is concerned with infestation of food stores and will usually identify the pests concerned and give advice on control measures.

### (c) **Preservation and despatch of specimens for identification**

Very often specimens are sent through the post badly packed or improperly preserved and they arrive in a condition which renders identification difficult or impossible. A few simple precautions will prevent exasperation on the part of the entomological expert and disappointment on the part of the inquirer.

#### *General points*

It is not generally realized that postal regulations prohibit the sending of live insects through the post; but in any case, it is usually more satisfactory to kill the specimens before despatch. A few drops of chloroform should be applied to the cork or stopper of the bottle or tube containing the insects. The more fragile insects (flies, mosquitoes, moths) are usually killed by 5 or 10 minutes' exposure to the saturated vapour; but more resistant insects (beetles, cockroaches, bugs) may require an hour or so. The insects should not be allowed to come in contact with the liquid chloroform.

The only other general point to emphasize is the seemingly obvious one of packing carefully to avoid damage in transit. Dry specimens can be sent in tins or *strong* cardboard boxes. Specimens in fluid are best sent in tubes, which can be sent in hollow wooden blocks made for this purpose, or else, well padded, in tins.

#### *Insect specimens*

Adults of most insects, and any moderately robust nymphs or larvae, retain their characteristic form and colour sufficiently well if merely allowed to dry without any special precautions (except under very damp conditions, when they may go mouldy). Dry insects are most easily handled if they are properly mounted on entomological pins, in which case they can be despatched in cork-lined boxes. However, it is usually nearly as satisfactory to send such specimens unpinned and lightly (i.e. not tightly) packed between layers of tissue paper and cotton wool.

#### *Insect larvae*

Almost all soft-bodied insect larvae are best killed and preserved by putting them into 70% alcohol (or 70% methylated spirit, 30% water). This is also the method of choice for soft-bodied or small and fragile adult insects (such as lice, fleas and psocids). It is a uniformly satisfactory preservative, which does little harm to most specimens. The only exception is in regard to aquatic larvae. These can be sent in water in which they were caught, if a little formalin is added, to give a solution containing about 2% formaldehyde. Aquatic specimens are useless without this preservative, as they rapidly decay in ordinary water.

#### *Mites*

Mites can be preserved and despatched in 70% alcohol. It is desirable to put them in a small volume of liquid in a small tube, otherwise there may be difficulty in finding them again, unless they are very numerous.

## IV · PEST INFESTATIONS INVOLVING LOCAL AUTHORITIES

### (a) Legal aspects

Sometimes domestic insect pests are sufficiently troublesome to involve legal liability; for instance where they are dangerous to health or a nuisance. Certain measures of legislative control empower local authorities and school authorities to deal with verminous conditions of either people, houses, or movable articles. 'Verminous' in this context is defined as infestation by such insects as bugs, fleas or lice and their eggs, larvae or pupae. In actual fact, 'verminous' applied to a person normally involves lice or scabies mites, whereas applied to a building it usually implies bugs or fleas.

#### (i) *Public Health Act, 1936, Sections 83-86*

##### *Public Health (London) Act, 1936, Sections 122-127*

The appropriate portions of these two Acts are generally similar in intention and operation, the one dealing with London being somewhat fuller in content. In brief they provide that, where it appears to a local authority, on the report of the Medical Officer of Health or a Health Inspector, that verminous conditions exist, they are entitled to proceed as follows:

#### *Cleaning or destruction of verminous articles (Sections 84 and (London) 122)*

This is to be done at the expense of the local authority and provision is made for compensation.

#### *Cleansing of verminous houses (Sections 83 and (London) 123)*

The local authority may serve notice on the owner to have the house properly cleansed and, in default, may carry out the cleansing and recover the cost. Where, however, it is deemed necessary to employ hydrogen cyanide fumigation, the operation is carried out by trained personnel and at public expense.

#### *Cleansing station (Sections 86 and (London) 124)*

Local authorities are authorized to set up (either separately or jointly) public cleansing stations provided with the necessary apparatus and staff.

#### *Cleansing of school children and inmates of common lodging houses*

This Section relates to the (London) Act, Section 126. The portion relating to school children, however, is generally applicable in respect of Section 54 of the Education Act, 1944.

A County Medical Officer, or a person authorized by him, has power to inspect children at County Council Schools, and if they are in a verminous condition, to serve notice on their parents or guardians requiring them to cleanse the child within 24 hours. In default of this, the child may be taken to a public cleansing station to be disinfested.

Similar powers of compulsory cleansing exist in respect to inhabitants of common lodging houses.

*Cleansing of verminous persons by order of Court (Sections 83 and (London) 127)*

Where a verminous person does not consent to treatment at a public cleansing station, the local authority may apply to a petty sessional court for an order to proceed with the case. The Court may then enforce attendance at the cleansing station under penalty for disobedience.

(ii) *Housing Act, 1936, Section 17*

Provision is made in this Act for local authorities to disinfest from vermin buildings scheduled for demolition.

(iii) *Hydrogen Cyanide (Fumigation) Act, 1937*

Under this Act the Secretary of State is given power to regulate the procedure of fumigation of buildings and to hold an inquiry into any accidents which occur in the course of such operations. The regulations governing the methods of fumigation are set out in the Hydrogen Cyanide (Fumigation of Buildings) Regulations, 1938.

(iv) *The Hydrogen Cyanide (Fumigation of Buildings) Act, 1938*

This requires notice of fumigation to be given, 48 hours beforehand, to the M.O.H. and local police station. It specifies the standards of training of the operators and details the precautions to be taken during fumigation. Aeration is described and also the precautions necessary before reinhabitation of the building.

(v) *Prevention of Damage by Pests Act, 1949 (S.I. 1950 No. 417)*

It imposes the duty on persons concerned in the manufacture, transport, storage and sale of food, of notifying the Ministry of Agriculture of infestations in premises or vehicles, in food or in containers likely to be used for food. An infestation is defined as 'the presence of rats, mice, insects or mites in numbers or conditions which involve immediate or potential risk of substantial loss or damage to food'.

Notification of infestations in a wide variety of imported foods is not essential in certain circumstances which are detailed in S.I. 1950 No. 416.

(vi) *Food and Drugs Act, 1955*

Proceedings may be taken under Section 8 of this Act, which refers to food 'unfit for human consumption'. The presence of insects, their dead bodies or excreta in food, however, could be defended in some cases, as not likely to cause actual illness. Accordingly, when prosecutions are brought under the Act (e.g. by a local authority) they usually rely on Section 2 which refers to 'prejudice of the purchaser . . . not of the substance or not of the quality demanded'.

(vii) *Food Hygiene Regulations, 1955*

These require businesses selling food for human consumption to keep their premises 'in such a condition as to prevent, so far as is reasonably practicable, infestation by

insects'. This does not apply, however, to food that has to be milled or processed before consumption.

(viii) *Insects as nuisances*

Infestations of unpleasant insects may sometimes be deemed statutory nuisances as defined in the Public Health Act, 1936. Thus, verminous houses might be covered by Section 92(1)(a) 'Any premises in such a state as to be prejudicial to health or a nuisance.' Similarly, accumulations of refuse or manure in which flies or other insects were breeding extensively and invading buildings might be dealt with under Section 92(1)(c) 'Any accumulation or deposit which is prejudicial to health or a nuisance.'

Legal action under these headings is taken by local authorities through their public health officers, and entomologists may be called as expert witnesses. It may be remarked that difficult points are often raised in these cases, such as the proof of responsibility for introducing bugs or fleas into a house, before or after a change of tenancy. Fortunately such actions are comparatively rare.

(b) **Functions of local health departments in regard to insect pests**

The principal duty of a local health department is the inspection and supervision of public health. In conducting this duty, the Medical Officer of Health and his Health Inspectors have the right of entry into houses which they believe to be infested; and the Medical Officer can require the medical inspection of persons who, from their contacts, are liable to infestation. (Public Health Act, 1936, amended by the Public Health Act, 1961.)

In addition to this supervision, local authorities are required, by the Public Health Acts, to provide certain facilities for the disinfection of persons and property. The more progressive health departments may wish to extend these services to improve the local standards of hygiene; for instance they may institute special campaigns for the eradication of bugs, head lice, scabies, etc. To carry out the operations entailed, special disinfection staffs are required; but it is very desirable for the Medical Officer of Health and the Health Inspector who supervise the work to be familiar with the various methods involved.

(i) *Disinfection of persons*

Local authorities usually set up cleansing centres for the cleansing of verminous people and their clothing. There are places where these centres are merely unused corners of the local public baths, or they are improvised in part of any building which happens to be available. It is surely not too much to expect that the disinfection centre of a large urban or metropolitan borough should be a properly designed building with adequate equipment and an efficient and self-respecting staff.

The principal treatments to be given are for head lice, scabies and body lice. The staff required must include men and women to deal with male and female patients. They must be careful, conscientious and preferably experienced. The

qualifications are put in that order because the modern treatments are not difficult but require thorough application to be effective. In connection with scabies treatments, bathing facilities are desirable; and for disinfesting clothing of people infested with body lice, a hot-air disinfestor may be required.

### (ii) *Disinfestation of buildings*

Until recently the only *reliable* method of disinfesting houses from bugs or fleas was by fumigation with hydrogen cyanide. On account of the dangerous nature of this gas, it is impossible to carry out treatments rapidly and easily. Alternative accommodation must be found for the inhabitants of the houses to be fumigated, and often for those in adjoining premises, for at least one night. Often it is necessary for local health departments to employ commercial operators at considerable expense because of lack of staff trained to the use of hydrogen cyanide.

In consequence of these difficulties, house fumigation with hydrogen cyanide was seldom done on the wide scale necessary for a radical reduction of bed bug infestation. Such alternative treatments as sulphur dioxide fumigation and the use of sprays were generally regarded as palliatives, seldom able to eradicate heavy infestations.

With the introduction of persistent synthetic insecticides, especially DDT, a simple and effective method of disinfestation is available which can be applied on a wide scale. It is beginning to be realized that every large borough should have at least one specially trained mobile disinfestation squad to carry out disinfestation by this method. The men should be provided with suitable equipment which will include protective clothing, hand-operated and power-driven sprayers and a small van. Teams of two men are adequate for room spraying. With hand-powered sprayers, they alternate in spraying and pumping up the compressed air. The labour and the likelihood of spilling insecticide are considerably reduced by the use of power-operated sprayers. Spray treatment of a small bedroom takes only about  $\frac{1}{4}$  hour with a power-sprayer and a little longer with hand-operated sprays. In contrast to a fumigation, the room is quite safe for occupation immediately after treatment.

### (iii) *Disinfestation of articles*

The use of DDT is not the answer to all disinfestation problems. Thus, it is sometimes necessary to disinfest the personal belongings of tenants before rehousing them; in which case a complete disinfestation of such articles as upholstered furniture, bedding and clothing is required within a few hours. The most satisfactory methods of achieving this are by heat or fumigation and it is highly desirable that local authority health departments should possess efficient apparatus for the purpose.

*Hot air disinfestation* is suitable for bedding, clothing and other fabrics which tend to absorb gases (especially hydrogen cyanide) and require very careful airing after fumigation to remove dangerous residues. Most urban authorities possess steam disinfestors for destroying germs but these are not entirely satisfactory for use against insect pests. The temperatures reached are unnecessarily high and the capacity is

relatively small so that the method is inefficient and slow for dealing with quantities of bedding and clothing. Suitable hot-air chambers are, however, rare.

*Fumigation* is the most suitable method of disinfecting large pieces of furniture which would be difficult to heat thoroughly right through; also polished wooden articles might be damaged by heat.

The treatment of batches of furniture can best be done in specially designed fumigation vans. The contents of one or two small houses are loaded into such a van which is then driven to a suitable fumigation site (in a reasonably isolated open space). After subsequent forced-draught airing, the furniture can be delivered to new premises on the same day.

Small-scale fumigation, by relatively non-toxic compounds such as ethyl formate, in boxes, bins or plastic sacks, has been revived as a convenient method of disinfecting clothing of people entering a clean environment (e.g. prison or public assistance hostel) (see pp. 136, 137).

## V · COMMERCIAL ASPECTS OF PEST CONTROL

### (a) **Insecticides**

The situation with regard to the manufacture, distribution and selling of insecticides in this country is briefly as follows. Primary insecticidal materials are either synthesized by big chemical manufacturers or else imported as raw materials by large firms. These large concerns are usually quite reliable in the specification of their products; but it is often inconvenient for them to sell insecticides direct to the user. Instead, they sell them in bulk to 'middlemen' who compound the materials in various ways and sell them to large purchasers or retail shops at an increased price. Very often they are entirely justified in doing this because they are charging for compounding the insecticides in forms suitable for use and for packing and distributing them. There are, however, certain firms who sell preparations of undisclosed composition and charge excessively for their secret formula.

Unlike patent medicines, secret insecticides are not legally required to print a declaration of ingredients on the container. It is, however, very desirable that a large purchaser (particularly on behalf of a health department or public institution) should find out the exact composition of the insecticides he buys. He will then be in a position to judge whether the price is reasonable and to compare the composition with officially recommended formulae.

Alternatively, if such a purchaser has decided on using a particular insecticide and wishes to know of reliable suppliers, he can obtain information from the Industrial Pest Control Association (86 Strand, London, W.C.2).

### (b) **Commercial pest control services**

Perhaps the earliest widely developed commercial pest control service is in the field of fumigation, which needs operators with regular experience. There are now increasing numbers of firms which undertake simpler operations for eradicating such pests as woodworm, bugs or cockroaches. Large hotels, restaurants and institutions, which are often chronic sufferers, may employ such firms to make regular visits

under contract. There is much to be said for this arrangement provided that the charges made are not excessive, for the commercial operators soon obtain a good deal of experience in the best materials and methods. Once again, however, it is rather desirable for a person authorizing treatments of this type in a public institution such as a hospital to be fully aware of their nature. There is no reason why payment should not be made for a service regularly and efficiently done, rather than for some quasi-magic remedy.

All the larger firms undertaking pest control services belong to the Industrial Pest Control Association mentioned in the previous section. This organization will supply a list of firms competent to undertake various types of disinfestation.

## 6. *Mechanical, physical and biological control measures*

### I. MECHANICAL MEASURES

Modern synthetic insecticides have achieved excellent results in many spheres; in particular, they have revolutionized the control of insect-borne diseases, especially in the tropics. These successes are not unqualified, however, as their regular use frequently leads to the emergence of resistant strains of the pests. Furthermore, the extensive use of chemical poisons has been denigrated on account of their possible danger to man and animals.<sup>6</sup> For these reasons, it may be desirable to review certain alternative measures, which may seem rather old-fashioned. It is worth remembering that certain insect-borne diseases which were formerly endemic in England were not eliminated by the skill or knowledge of doctors or entomologists, but died out as a result of the changing habits of the citizens. Thus, malaria receded as agricultural practices changed and improved; typhus died out when body lice became exceedingly rare; plague has long been extinct since better housing prevented close contact with the black rat and its fleas.

#### (a) **Cleansing operations**

The importance of cleanliness in reducing liability to insect pests is very often stressed. There are several ways in which domestic hygiene handicaps the pests. Firstly, infestations tend to be discovered early in well-regulated houses and they can be 'nipped in the bud' before colonizing many inaccessible harbourages. Secondly, the actual cleaning operations may destroy the insects (e.g. frequent combing removes and destroys head lice; laundering clothes kills body lice; scrubbing of woodwork often kills bug eggs). Thirdly, cleanliness prevents the accumulation of rubbish which may provide food for some pests (e.g. spilt foods for stored product pests) and shelter for others (e.g. debris necessary for the development of flea larvae). Analogous to cleanliness is the maintenance of a warm, well-ventilated house which is inimical to those pests which require damp conditions to flourish.

On a larger scale, cleanliness is very desirable in warehouses and similar large food stores; and the Ministry of Agriculture Infestation Division have usefully employed vacuum cleaners in such buildings to remove debris. Another type of hygiene concerns the elimination of waste products (see Chapter 12). A water-borne sewage system, almost universal in Britain, protects us from the swarms of flies and blowflies which can breed in primitive privies in a hot summer. The frequent removal and disposal of domestic refuse is essential to prevent flies breeding in dustbins. The household can help by keeping the bins in good condition and the lids in place.

### (b) Screening

To cope with widely distributed pests whose breeding grounds are numerous or unknown, a logical method of protection is to exclude them by fine-mesh screening. Screening material exposed to outdoor weathering must be proof against corrosion and may be made of galvanized steel, copper, phosphor bronze or aluminium. The size necessary to exclude various insects depends on the aperture, which is determined by the mesh number (holes per linear inch) and the thickness of the wire. Wire thickness is defined by standard wire gauge (swg) numbers, the following being representative:<sup>(5a) (9)</sup>

20 = 0.036 in. or 0.914 mm

30 = 0.0124 in. or 0.315 mm

25 = 0.020 in. or 0.508 mm

35 = 0.0084 in. or 0.213 mm

Some suitable specifications for excluding different insect pests are as follows:

<i>Mesh No.</i>	<i>swg</i>	<i>Aperture length</i>	<i>Excludes</i>
10	32	0.0892 in. (2.27 mm)	Houseflies, blowflies, etc.
16	31	0.0510 in. (1.3 mm)	Most mosquitoes
18	33	0.0455 in. (1.15 mm)	All mosquitoes
20	27	0.0336 in. (0.853 mm)	Sandflies

It must be remembered that apart from reducing light, screening reduces air flow and thus cuts down ventilation, largely in proportion to the fineness of the mesh.

There are also other difficulties, and the complete screening of a large building is not generally feasible unless the windows have been specially designed for it. Thus, the screening must be restricted to ventilation windows, or it will cut off too much light. Such windows will not be able to open outwards (as usual) because of the screens. Attention must be paid to ensuring door closure with self-closing springs, since it is useless to exclude insects from the windows if they can enter elsewhere.

Simple screening measures can be adopted by the householder. Thus, food can be protected from flies and blowflies by a wire-mesh safe and, on the table, by meat or milk covers. Where outer doors are kept open in summer, hanging bead screens may give a limited protection from flies. Another type of screening, on a small scale, is the protection of clothing from clothes moths by sealing it in paper or plastic bags before storage.

### (c) Trapping

On the whole, trapping is a very inefficient way of trying to combat insects. Owing to their extraordinary powers of rapid reproduction, their numbers are seldom noticeably diminished by even the most efficient traps. As a rule, the only possible advantage is to achieve a temporary local reduction.

One of the most simple and effective traps is the old-fashioned sticky fly paper, the great merit of which is its simplicity and the main disadvantage its unsightly appearance. A number of fly papers hung up in a room will achieve some reduction in numbers, provided that re-invasion from outside is not too rapid. More elaborate traps are seldom worth using, except in rural areas liable to a fly nuisance (e.g.

near poultry farms or piggeries). In such places, some relief may be obtained by a simple trap consisting of a cage with a 'no-return' conical inlet in the bottom, which is raised an inch or so above an attractive bait. Many varieties of this trap have been used in various countries, one well-known type, formerly much used in Britain, being the 'balloon fly trap', so called because it is spherical in shape. The traps are used at suitable locations out of doors where a malodorous bait would not be objectionable. Chicken entrails<sup>(10)</sup> may be used or the following mixture: 250 gm yeast are stirred into 1.5 litres of water and kept at room temperature for 3 days.<sup>(20)</sup> 10 gm ammonium carbonate are added and the bait is ready for use (it can be poured over bread, etc., in a shallow dish). The mixture will keep for some time in corked bottles, though fermentation sometimes causes the corks to fall out.

A housefly attractant may also be used to 'trap' eggs laid on an artificial medium, which can then be destroyed. Russian workers have found that a solution of ammonium carbonate (10–20%) poured over bran will attract flies and induce them to lay freely on it.<sup>(26)</sup> This method has not been widely adopted, however.

Trap baits have been used against that persistent pest of hospitals and institutions, Pharaoh's ant. Attractive scraps of food are scattered about and, when crowds of ants have collected on them, they are collected and plunged into boiling water. Using this method, an official at one institution destroyed approximately  $5\frac{1}{2}$  million workers and 6310 queen ants over a period of 678 days without eradicating the pest!

In the past, primitive traps of crumpled paper have been used to collect bugs from infested beds, for burning in the morning. Leaves of the runner bean have been used for this purpose in the Balkans,<sup>(4)</sup> their special value being the presence of tiny hooks, which can catch bugs and similar insects.<sup>(22)</sup> In India, a bug trap consisting of two hinged strips of wood, with grooves for the bugs on the inner faces, has been used to collect specimens from natural infestations.<sup>(27)</sup>

Cockroach traps have been sold in this country, the commonest form being shaped like a spittoon with the entrance guarded with hinged metal flaps. A bait is put in the centre and the roaches are expected to attempt to reach it, but they fall inside as the metal flaps give way. This trap may catch the 'black beetle' type of cockroach (*Blatta*) but the more agile climbing German roach (*Blattella*) can climb out of it.

#### (d) Mechanical destruction

The violent destruction of insects by mechanical means (as by a 'fly-swatter') is an obviously inefficient way of destroying insect pests in any numbers. In one sphere, however, mechanical destruction on a large scale has been found practical. Stored grain or seeds of various kinds as well as milled products, which have become infested with weevils or other pests, may be disinfested by passing through a machine known as the 'Entoleter'. The cereal is spouted into the machine and flung out by centrifugal force between two flat steel discs revolving rapidly on a central shaft (about 1500 rpm for wheat to 3000 rpm for flour). These discs are studded with small round posts of hardened steel, set in two concentric rings. The impact of the cereal against the revolving discs and posts and against the housing of the machine, is so great that all stages of insects and mites (including the egg) are killed.

### (e) Vacuum

The creation of a vacuum is an unusual method to be used against insect pests, but it has been employed once or twice and is included here for the sake of completeness.

The fall in pressure consequent on evacuation of air is harmless to most insects on account of their small size and comparatively robust structure. Therefore, a vacuum merely acts as does deprivation of oxygen, the effect of which will be discussed later.

## II · PHYSICAL MEASURES

### (a) Heat

Insects are not very resistant to high temperature; they die if their bodies are raised to about  $60^{\circ}\text{C}$  ( $140^{\circ}\text{F}$ ) for 5 or 10 minutes (see Table 3, p. 60). The destruction of insects by heat has been quite widely practised, both for disinfecting articles (e.g. clothing, bedding, wooden articles and food) and for disinfecting premises. The use of heat does not call for any special experience. Such risks as do exist (scorching, fire) are obvious to the simplest workman. Though heat treatment clearly cannot have any lasting protective action like some modern insecticides, it is usually cheap and often immediately effective. There are, however, certain difficulties limiting its usefulness which will be discussed shortly.

Theoretically, there are various methods of applying heat. Radiant heat is seldom satisfactory since it is difficult to apply evenly and may cause too high superficial temperatures. On a small scale, the use of blowlamps to destroy bed bugs provides an example of this method, but it is only used in buildings where scorching of paintwork is comparatively unimportant.

A more satisfactory method is to rely on heat exchange by conduction. For applying the heat, water, steam or hot air can be used.

Water is very effective in many ways but immersion in water is often a grave disadvantage and sometimes impossible. Nevertheless, it is worth noting that such a simple expedient as soaking clothing in hot water (over  $60^{\circ}\text{C}$  or  $140^{\circ}\text{F}$ ) for a short time will destroy all vermin, even though it results in wet garments to be dried afterwards.

Steam is employed in steam sterilizers for disinfecting bedding from fever patients, etc., in such apparatus as the Washington Lyon. Machines of this type are designed for the more difficult task of destroying bacteria and, to this end, a very high temperature is produced by steam under pressure, followed by evacuation and repeated steam pressure. The method is unnecessarily slow, cumbrous and expensive for destroying insects and furthermore, the articles are left in a damp condition, necessitating drying with hot air. Similar reasons render steam unsatisfactory for other types of disinfestation, viz. the unnecessarily high temperature (sometimes causing damage, for example, to polished wooden articles and leather goods) and the dampness finally produced.

Hot air is the most satisfactory heat-disinfecting agent for destroying insect pests. Any desired temperature can be achieved and the articles are left finally in a dry

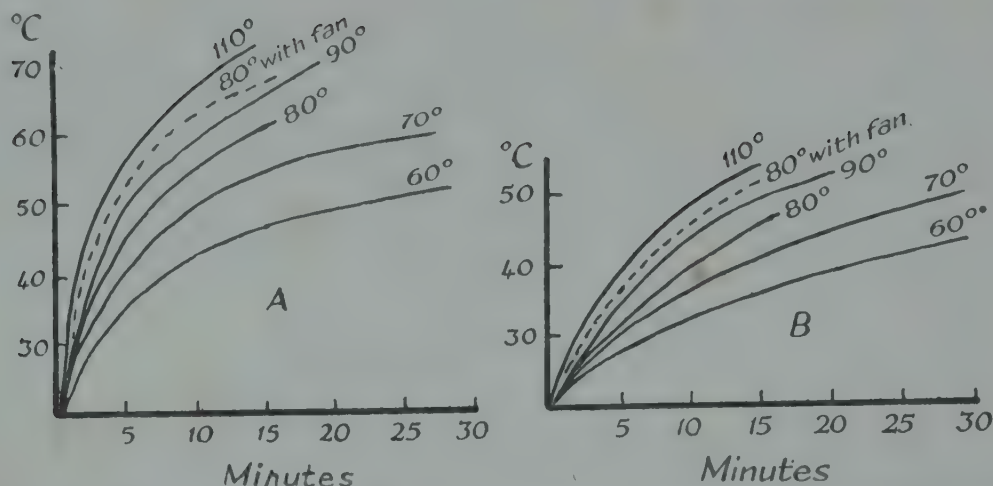


FIG. 9. The penetration of heat through fabrics. Ordinates: temperatures recorded by thermocouples under (A) one and (B) three layers of blanket. Abscissae: time in minutes. Curves are marked with the respective external air temperatures; in one test the air was circulated by a fan. (After Busvine, 1944, *Bull. ent. Res.* 35, 115.)

condition. Hot air, however, has its own disadvantages. Air has a low thermal capacity and it is a poor conductor of heat. Furthermore, since hot air is lighter than cold air, there is usually a sharp temperature gradient in any heated chamber from the cold floor to the hot ceiling. These disadvantages have handicapped hot-air disinfestation to a considerable extent. Added to them must be the poor conduction of heat through many articles to be disinfested, for example, clothing and bedding fabrics which are specially constructed to be heat insulators. This obstacle is illustrated by Fig. 9, which shows the lag in penetration of heat through layers of quite poor quality blanket materials.

Owing to the protecting effect of the fabrics, wood or other substance in which the insects are embedded, the exposure times and temperatures necessary in practice are enormously greater than those necessary to kill the unprotected insects. Furthermore, some of the materials to be disinfested may be damp and a considerable amount of heat will be lost in drying them (latent heat of evaporation of water!).

In recent years, it has been realized that the disabilities of hot-air disinfestation can be mitigated by forced draughts induced by air circulation. Thus local cooling due to the low heat capacity of air and its poor conductivity is obviated by continual movement across the sites of heat transfer. Again, the layering of hot air and its consequent bad distribution is reduced by mixing of the air throughout the chamber. Finally, where fabrics are concerned, they are more likely to be penetrated by moving air currents than by still air.

So far as domestic and medical pest insects are concerned, by far the most important use of hot air for disinfestation is for treating clothing and bedding suspected of harbouring bugs or lice. Kiln sterilization of timber to destroy wood-boring beetles is also important; but this is more of a commercial process than a matter of domestic hygiene.

Heat treatment of rooms to eradicate bed bugs has been practised, but it was difficult to ensure success owing to the layering effect mentioned above and also

the poor penetration of hot air into structural crevices. Consequently, this method has fallen completely into desuetude with the advent of more modern methods.

Hot-air treatment of buildings to destroy the boring beetle *Hylotrupes bajulus* was formerly practised in Denmark; but the apparatus necessary is elaborate and the method has never been adopted in Britain.<sup>(13)</sup>

### *Hot-air disinfestation of clothing and bedding*

Prior to the advent of DDT, the usual method of combating lousiness among troops on active service was by hot-air disinfestation of clothing and bedding. Various types of mobile disinfestors were described in the British Army Manual of Hygiene, culminating in the 'Millbank' apparatus, introduced in the Second World War, which employed the forced-draught principle.<sup>(23)</sup>

Two serious disadvantages hamper hot-air disinfestation; it is slow and it does not protect the treated clothing from immediate reinfestation. Consequently, it was never able to prevent the chronic lousiness of front-line men in the First World War. Finally, the remarkable success of DDT dusting in the Naples typhus epidemic (1943) rendered hot-air disinfestors obsolete for dealing with large-scale lousiness, especially during an epidemic.

There is, however, some justification for retaining hot-air disinfestation for the routine delousing of vagrants. In some countries, regular disinfestation of infested people by modern insecticides has provoked DDT resistance in some areas, so that this insecticide might no longer prove effective if the calamity of a typhus epidemic occurred.

If it is desired to improvise a workable hot-air disinfestor for use in an urban community, it is simply necessary to adapt a small room by insulating it as well as possible and suitably lagging the door. Heat can be generated by a stove or by hot water or electric radiators. All that is necessary now is to provide hooks or rails on which to suspend the garments or bedding so that they hang separately and loosely in the upper part of the chamber *where the temperature is above 70°C (158°F)*. Provided that the insect pests are not protected by more than the equivalent of two thicknesses of blanket, an exposure of one hour at this temperature should be effective.

A much more reliable and more rapid disinfestation plant is obtained if an air circulation system is installed. It is possible to improvise this arrangement in an existing room or chamber by constructing ducts containing a fan to extract air from around the top of the room and inject it again round the bottom. A specially designed disinfestor of this type was produced by the Gas Company for the Ministry of Home Security in the Second World War.<sup>(2)</sup> It was intended to disinfest bedding from air-raid shelters and had a working capacity of 380 blankets per hour.

### *Disinfestation of foodstuffs by heat*

Small quantities of food in domestic larders may develop infestations of various stored product insect pests (see p. 325). It is comparatively easy to destroy these pests by heat in dry foods such as flour, rolled oats, various cereals and spices.

Lightly infested food treated in this way should be quite safe to eat provided there are no squeamish objections. In any case, it should be fed to animals unless the food value is very badly deteriorated.

To allow for penetration of heat through a mass of food, an exposure of 1 to 1½ hours to a temperature of 100°C (218°F) may be necessary. The food should be heated at atmospheric pressure in closed tins in a moderate oven. Biscuit tins do very well for this purpose; their lids should be kept on during the subsequent cooling in order to conserve moisture.

#### *Kiln sterilization of wood infested with beetle grubs*

Heat treatment is one effective method of destroying various types of wood-boring beetle larvae (see p. 388) either in unworked wood or in furniture, plywood, etc. The exposures necessary with different temperatures and humidities have been determined for the commonly occurring powder-post beetles (*Lyctus* spp.) and these probably hold for other wood-boring grubs. The steam-heated kilns which are used industrially for this purpose, can be operated at various combinations of temperature and humidity. Moisture saturated air is more rapid in action but lower relative humidities have the advantage of preventing appreciable changes in the moisture content of the wood and surface wetting, due to moisture condensation, on cooling. The latter is sometimes detrimental to French-polished articles.

The periods for which timbers of various thicknesses must be heated are given, with other details, in a Forest Products Research Laboratory leaflet. They range from 2½ hours for a 1-inch and 6½ hours for a 3-inch plank at 55°C, 8 to 12 hours for these two planks at 50°C and about 48 hours at 47°C.

#### (b) **Cold**

The data in Table 2 (p. 59) show that the resistance to low temperatures varies considerably in different insects and depends to a large extent on the previous environment of the insect. These data are for exposed insects and in considering pests protected in various ways, the same principles apply as in hot-air disinfestation. Thus the 'penetration of cold' (i.e. progressive loss of heat) is retarded by the bad conduction of heat in many articles to be disinfested. Consequently it is necessary to submit them to considerably lower temperatures or for longer exposures than those necessary to kill the exposed insects. For example, all lice and their eggs are killed by an exposure to air at -20°C (-4°F) for 4 hours; but a period of 12 hours at this temperature might be necessary to disinfest a thick fur or woollen garment. In certain parts of the world where the night temperatures during winter fall to such very low levels, it might, under some circumstances (e.g. a typhus epidemic) be advisable to take advantage of the fact to delouse clothing. But, in general, cold treatment of articles of disinfestation is clearly much more difficult and expensive than other methods. Disinfestation by chilling is clearly out of the question for rooms or buildings.

Whereas the disinfestation of articles by refrigeration is not practical, it is feasible, on a limited scale, to protect them from damage by cold storage. All insect activity is inhibited by temperatures about 5°C (40°F) though some species can survive

very long exposures to these conditions (e.g. clothes moth larvae have survived 12 months at such temperatures). This method of preventing insect damage is relatively expensive so that it is only likely to be employed to protect such things as valuable carpets or fur coats from clothes moths or carpet beetles, while in storage.

TABLE 4 *Resistance to asphyxiation by carbon dioxide of various insects*

Species	Stage	exposure (hrs)
<i>Sitophilus granaria</i>	Adult	213
<i>Sitophilus oryzae</i>	Adult	68
<i>Anagasta kuhniella</i>	Larva	54
<i>Tribolium castaneum</i>	Adult	30
<i>Cimex lectularius</i>	Adult	15

After BUSVINE, J. R. (1942) *Nature*, **150**, 208

### (c) Asphyxiants

When the respiratory system of insects was described, it was pointed out that they are remarkably resistant to deprivation of oxygen. This is illustrated by Table 4, which gives the average exposures to CO<sub>2</sub> necessary to kill certain kinds of pest insects. It will be seen that they range from  $\frac{1}{2}$  to 8 days! It is therefore clearly impossible to expect to drown insects by immersing them in water for a few hours.

At the time of the First World War, it was suggested that stores of grain could be protected from attack by stored product pests, by sealing the grain in air-tight silos or other containers. In theory, any insects present in the grain would be asphyxiated after the oxygen had all been used up. Comparatively little attention was paid to this method of grain storage until, shortly before the Second World War, interest was revived by some French trials. The method was put into practical use in Argentina during the war, at a time when grain could not be exported and had to be held for long periods. Subsequently, further investigations were conducted in Britain, the U.S.A. and Russia. A practical development has been the recent (1955) erection of eight 1000-ton storage bins in Cyprus. Work in Britain with a comparatively small container (7 tons) has shown how the method could be adopted for use on farms.<sup>(12)</sup>

An alternative method of asphyxiating insects is to occlude the respiratory system by clogging the main tracheae or merely blocking the spiracles. It is even possible that water might achieve this if, by addition of a wetting agent, it is enabled to penetrate the spiracles. This is probably the basis of the moderately effective action of soap and water sprayed on plants to control aphids. Clogging of the tracheae may also be one of the modes of action of the mineral oil emulsions used against orchard pests or the oil films applied to ponds to destroy mosquito larvae.

It would be misleading to suggest that all oil type insecticides rely on an asphyxiating action; very often the inert oil contains toxic substances, either as impurities

or specially added to enhance its effect. For the reasons already stated, the asphyxiating action is not highly reliable in controlling insects and the role of oils has gradually shifted from that of principal toxic agent, to that of mildly toxic carriers of pharmacologically active substances. They will be considered from this point of view in a later section (p. 133).

#### (d) Dehydrants

The delicate water balance of insects has been referred to in an earlier chapter (p. 55). Owing to a relatively large surface area compared to volume, a very small animal is liable to harmful desiccation in dry air. Insects living in such conditions are protected by cuticles which prevent water loss mainly by virtue of an exceedingly thin waxy outer layer. It has been found that certain mineral dusts damage this layer and cause the death of the insect from desiccation.

The story is a rather complex one, beginning with the empirical observation that certain dusts mixed with grain protect it, to some extent, from damage by weevils and similar pests. (This is said to have been known 2000 years ago by the ancient Egyptians.) The subject attracted the attention of biologists in recent years and the principles involved have been gradually discovered. It was first shown that dusts of quite different chemical constitutions were effective provided they were fine enough; it was also found that dusts with hard sharp particles were more effective than softer substances. These facts suggested that the action was physical or mechanical rather than chemical. Secondly, the insects dying from the action of the dust were observed to lose water very rapidly, the lethal action being much more rapid in a dry than in a moist atmosphere. The inference was that the dusts were causing a harmful water loss from the insects, in some way. It was shown that the dusts acted without entering the spiracles of the respiratory system and that, although the dust was normally swallowed with the food, it was also effective in desiccating pupae which do not feed. The site of action is therefore limited to the cuticle, which loses its waterproofing powers following the disruption of the waxy epicuticular layer. Some workers attribute this action of finely divided dusts primarily or entirely to their abrasive action.<sup>(14, 30)</sup> Other investigators, particularly in more recent years, have recognized that adsorption can be the dominant factor in removal of lipid from the epicuticle. This controversy is of more than academic interest. If the desiccating action of the dusts is due to abrasion, they are only likely to be effective against insects whose habits render them liable to this process; for example, granary beetles, which constantly rub their bodies as they crawl among the grain. If, on the other hand, the epicuticular wax can be removed by adsorption, a wide variety of insects with different habits and habitats should be susceptible to the lethal effect of the powders.

Possibly both types of desiccating action can occur in different circumstances. It is noteworthy that most of the earlier work supporting the abrasion theory was, in fact, done with grain weevils. The essential qualities of the dust required were hardness (preferably above 6.5 on Moh's scale) and fineness (mainly between 1 and 5 microns).<sup>(14)</sup>

More recent work on sorptive powders has shown, as predicted, that they can be

used against a wide variety of arthropod pests.<sup>(11)</sup> The essential characters are a porous material with a large specific surface, which can be shown to absorb wax. Dusts with a pore size ranging from 20 to 300 Å and a specific surface of over 100 m<sup>2</sup>/gm are most effective. The most promising materials, which have been exploited commercially in the U.S.A., are silica aerogels (e.g. 'Silikil').

Desiccant dusts, as one might expect, are more rapidly lethal to insects in dry conditions. The more efficient types, such as the silica aerogels, will nevertheless continue to cause water loss at very high humidities. Their lethal action on insects is in some way accentuated under moist conditions if a monolayer of ammonium fluosilicate is applied to the aerogel. This modified powder kills cockroaches and fleas as rapidly at 100% relative humidity as in drier air. It is suggested that the removal of the lipid layer allows the fluoride access to the aqueous protein layers of the cuticle and thus initiates poisoning.

#### (e) **Electrocution**

In a laboratory in Savannah, U.S.A., a device is used to kill flies escaping from a breeding colony, without insecticides. It consists of a wire grid over the window charged with high-voltage electricity in such a way that flies touching two adjacent wires would be electrocuted. This worked effectively, but it must be admitted that the periodic hiss followed by a smell of burnt fly is somewhat disconcerting. A similar device is used outside a hotel in Entebbe, Uganda, to kill midges at night.

#### (f) **Radioactivity**<sup>(1)</sup>

The development of atomic reactors for nuclear power has resulted in the incidental production of radioactive by-products which have been put to various uses; one of these is the destruction or sterilization of insect pests. A constant and controllable radioactive source is required for this purpose, preferably one emitting  $\gamma$ -rays at an adequate energy level. It might perhaps be possible to separate a suitable isotope from the mixture of waste fission products; but the most convenient source, in fact, is cobalt-60, an isotope produced by the spare neutron flux available in nuclear reactors. This produces  $\gamma$ -rays at two energy levels and has a half-life of 5.3 years.

The effects of  $\gamma$ -radiation on tissues depends on the dosage, which is measured in roentgens (r) or rather similar units (reps or rads). While all cells are damaged by high doses, actively dividing cells (as in the genital system) are more sensitive to lower doses, which can cause sterility; and still smaller amounts of radiation may induce mutations (usually harmful) in the progeny of a treated animal.

For reasons which are unknown, different forms of life differ considerably in their sensitivity to radiation. Insects generally are much less sensitive than higher animals and enormous doses (over 300,000 r) may be necessary to kill them rapidly, while about half this dose would be lethal in about a week.<sup>(7)</sup> This contrasts with a mere 600 r which is lethal to man.

The large doses necessary to kill insects, together with various difficulties and precautions, render the direct destruction of pests by this means uneconomical. Accordingly, the main use of radioactivity in pest control is to produce sterile males

for release to decimate the natural wild population (as described under biological control, below).

Sterility can be caused by dosages between 2000 r and 20,000 r (as compared with 300 r in man). The relations between dose of radiation and effect may be represented by the normal curve of distribution in the population; a few individuals being easily affected, a few being resistant, while most cluster round the average. For this reason, it is difficult to decide the exact dosage for sterility, since a few tolerant individuals straggle up into the higher dose range. At this level, though well below the dose causing 50% mortality, the lethal effect begins and it may be difficult or impossible to find a dose which will cause sterility without some curtailment of life. A compromise must be made and the doses which have been chosen, to sterilize various flies and mosquitoes for field trials, range from 2000 r to 18,000 r.

### III · BIOLOGICAL MEASURES

It should be emphasized that most of the methods discussed in this section are only in the experimental stage, at present, and none has been successfully employed in Britain. Nevertheless, the subject has attracted much attention as a possible alternative to insecticides, which have become somewhat handicapped by the growth of resistance and increasing complaints about toxic hazards. Ruth Carson, for example, has suggested that insufficient attention is paid to biological control;<sup>(6)</sup> therefore it is useful to know something of the possibilities and limitations of such methods.

#### (a) Sterilization procedures

It is convenient to group sterilization procedures together, since they involve the mating behaviour of insects, even though the sterilization may be physical (radioactivity, p. 87), chemical (chemosterilants, p. 89) or biological.

##### (i) *Release of radioactively sterilized males*<sup>(16)</sup>

The idea of checking populations of insects by releasing sterile males has been developed in the U.S.A. over a considerable time, beginning with a suggestion of E. F. Knipling about 1938. The method has achieved remarkable success in the eradication of the screw-worm fly (*Cochliomyia hominivorax*) from the island of Curaçao and the Florida peninsular; but it is far from applicable to all pests, since the following criteria must be satisfied:

- (1) The females must mate once only or rarely more than once, so that after mating with a sterile male, they are rendered infertile.
- (2) It must be possible to find a dose of radiation which will sterilize virtually all males, without much effect on their behaviour or longevity.
- (3) A mass-rearing technique must be available.
- (4) The insects must be easily distributed and mobile.
- (5) The wild population must be small in relation to the numbers of sterile individuals which can be released.
- (6) Since the aim is complete eradication, an island or an isolated infested area must be chosen.

The operations against the screw-worm, which are the only successful field campaigns to date, were enormous undertakings. The area of Florida cleared was 70,000 square miles and it needed the release of 2000 million flies over 18 months. More than 40 tons of meat were used to breed the flies and 20 aircraft employed to distribute them.

Experimental field trials have been conducted with mosquitoes (southern U.S.A.),<sup>(21, 28)</sup> sheep blowflies (Scotland)<sup>(19)</sup> and houseflies (Italy);<sup>(24)</sup> but none was very encouraging. Perhaps the main difficulty is the size of natural populations of insects, which approximate to the following numbers per square mile: screw-worm flies, 500; tsetse flies, 1000; sheep blowflies, 50,000; mosquitoes,  $\frac{3}{4}$  million.

From a little reflection, it is evident that the efficiency of the sterilization method is just the opposite of that of insecticides. The latter easily achieve initial reductions, but become less and less efficient in killing the last few percentages of the insect population. With sterile male release, however, the main difficulty is to make the initial reduction. If this succeeds, the last few normal females have less and less chance of escaping the growing preponderance of sterile males. For this reason, sterile male release against populous insects might perhaps be feasible, if the wild population was first reduced by other measures (e.g. insecticides) or was low because it had newly colonized new territory.

#### (ii) *Sterilization of populations by chemosterilants*<sup>(15, 25)</sup>

Chemicals capable of causing sterility in insects or other organisms are called chemosterilants. Their nature and physiological effects are discussed on pp. 110–112; this section deals only with their potentialities for controlling insect populations.

Various articles have made theoretical comparisons between the release of sterile males and the use of chemosterilants. The latter starts with the basic advantage that both males and females in the wild population are sterilized. One can make a comparison between (i) release of 10 sterile males to each normal one and (ii) use of chemosterilants to sterilize 9 out of 10 of both sexes. In both cases, only 10 males in 100 will be fertile; but in case (i), each will meet a normal wild female, whereas in case (ii), 9 out of the 10 will meet sterile females. Obviously this could cause a more rapid population decline, though the reductions which have been calculated are very hypothetical.

Chemosterilants, however, suffer from one very great disadvantage: their danger to higher animals and man. This limits their use as much as the most toxic insecticides, though they can be used both by contact or ingestion. For stomach action, they can be incorporated in baits; this has been tried in field trials against houseflies, applying the bait to remote refuse dumps where it is not likely to do harm.<sup>(17, 18)</sup> For other insects, attractants (possibly sex lures) may be tried, to bring them into contact with a chemosterilant source. Alternatively, chemosterilants can be used to produce sterile males for release as described in the preceding section.

#### (iii) *Release of insects carrying harmful genes*<sup>(8)</sup>

Populations of most insect species (like man) carry small numbers of harmful genes, usually in the recessive form. It has been suggested that it might be possible

to select strains carrying high proportions of deleterious genes which, while permitting laboratory rearing, might severely handicap insects in nature. A sustained release of such gene carriers might transmit these harmful traits to the wild population.

Alternatively, it is known that certain sub-species of several insects, while freely mating together, produce more or less infertile offspring. This represents another way of decreasing wild populations.

Both these methods are being explored in genetical laboratories, but neither has yet reached the stage of practical trial.

### (b) Control by parasites and predators<sup>(29)</sup>

Natural populations of insects, like other animals, are to some extent limited by the depredations of predators and the regular toll of lethal parasites. Environmental factors which alter the balance, by favouring either the animal or its parasites or predators, can greatly alter the population size. The use of parasites or predators, for controlling insect pests, has been attempted on many occasions in the past few decades, with varying success. The principal successes have been among agricultural pests, especially when the pest has been able to colonize a new country without bringing along the parasites or predators which held it in check in its homeland. Unfortunately, there seem to be fewer obvious biological checks of this kind for insects of public health importance than for other pests; however, a renewed search is being made.

A wide variety of different organisms can act as parasites or predators of insects; they range from viruses to mammals. Among insects of medical importance, there is evidence of mosquito larvae being heavily parasitized by fungi (*Coelomomyces*) and Microsporidia (*Nosema* and *Thelohania*) while adults may be attacked by the fungus *Entomophthora*. Housefly eggs are apparently eaten in quantities by mites (Macrochelidae)<sup>(3)</sup> while the adults, at certain times, are attacked by *Entomophthora* (*Empusa*). While these facts are of interest and deserve further study, there are many unsolved difficulties of mass culturing and dissemination of these parasites and none has been used successfully in practice.

One of the few organisms pathogenic to insects, which has been extensively used, is the bacterium *Bacillus thuringiensis*.<sup>(5)</sup> While this has been mainly tried for agricultural insects, there have been moderately promising trials of its use as an additive to food of chickens, to prevent flies breeding in their droppings.

It has been known for over 100 years that insects suffer from virus diseases, but it was not until the development of the electron microscope that the various causal organisms were positively identified. They are classified in four arbitrary groups, of which the polyhedral virus diseases are best known. These are so-called because of the growth, in the insect tissues, of large numbers of polyhedral crystals which contain the actual virus. Some forms develop in the cytoplasm of the cells, others in the nuclei. Generally speaking larvae of Lepidoptera are most prone to infection (e.g. clothes moth grubs); but it is difficult to manipulate the disease for control purposes.

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## 7. *Chemical control measures*

### I. INTRODUCTION

#### (a) **History of the chemical control of insects**

The word *insecticide* is only about a hundred years old and it is only during the last half-century that any considerable progress has been made with this method of controlling insect pests. It is true that since ancient times there have been intermittent records of various substances being used to destroy insects, most of them based on folklore or upon such writers as Pliny. Few of these nostrums are reliable, however, because they are so often based on specious logic rather than on reason and experience. Thus parts of a plant having a fancied resemblance to a noxious pest were often believed to be a specific for destroying it.

The development and wide use of insecticides has gone step by step with general technological progress. Not only has scientific research replaced random trial and error in the search for suitable materials but the number of substances available has enormously increased. In early times, only simple minerals and crude plant products could be obtained. Inorganic minerals such as the salts of heavy metals and arsenical compounds, which were known to be toxic to man and other animals, were among the first substances to be used effectively against insects. Several efficient vegetable insecticides, also, have been used in a crude form for so long that their original empirical discovery is unknown or forgotten. Nicotine as tobacco dust or infusion was used in western Europe as early as the eighteenth century. The value of pyrethrum was apparently discovered by the Persians, who guarded the secret of their wonderful insect powder until it leaked out to Europe with an Armenian merchant early in the nineteenth century. In the latter half of that century, as chemical industry developed, a large number of by-products became available and some of them were found useful as insecticides. In particular the huge industry connected with coal-tar distillation in Britain and petroleum in the U.S.A. provided a wide range of organic chemicals.

With advances in chemical technique, the vegetable products of proved efficiency could be analysed and their effective ingredients isolated or standardized. For example, the active principles of pyrethrum and derris were discovered in the early decades of this century. The latest phase has been the development of a wide range of synthetic organic compounds with high insecticidal activity and, in some cases, much less poisonous to higher animals. The first of these was DDT, which can be said to have opened a new era of insect control. Other chlorinated hydrocarbons followed, then a great variety of organo-phosphorus compounds and carbamates as well as synthetic analogues of pyrethrum.

The new synthetic insecticides, being relatively cheap, stable and easy to use, have been very widely employed. Production of insecticides increased about a hundred-fold in the U.S.A. between 1938 and 1961. In addition to extensive use in

agriculture, the remarkable successes of insecticides against insects of public health importance has radically changed the methods of controlling insect-borne diseases, especially in the tropics.

These achievements, however, are offset by two serious problems: the development of resistance in many of the pests and the growing concern about toxic hazards to man, his livestock and wild life.

### (b) Common names for pesticides

The great multiplication of organic chemicals used as pesticides has introduced many compounds with names too complicated for general use. Accordingly, shortened forms and trade names were employed; but as several of these could apply to the same compound, confusion arose. There was clearly a need for short common names, on the lines adopted for pharmaceutical products. Britain took the lead in standardizing these names, when a Committee on Common Names for Pesticides was set up by the British Standards Institution in 1950.

Devising common names for pesticides is less simple than it might appear, since a new name must avoid confusion with existing patented names in the same field. The B.S.I. periodically publishes up-to-date lists of approved names, together with their chemical designations and structural formulae. In contrast to proprietary names, these common names are written or printed without capitals, e.g. heptachlor, parathion. In the exceptional cases where the names are formed of initials, they should be written in capitals without intervening stops, e.g. DDT.

Despite the convenience of standard common names, many commercial and other designations are still present in the literature. The following list gives B.S.I. equivalents of some of these.

Alodan:	chlorbicyclen	Lindane:	(pure) <i>gamma</i> BHC
Asuntol:	coumaphos	Muscatox:	coumaphos
Baytex:	fenthion	Phosdrin:	mevinphos
CoRal:	coumaphos	Resitox:	coumaphos
DDVP:	dichlorvos	Rogor:	dimethoate
Delnav:	dioxathion	Ronnel:	fenchlorphos
Dicophane:	DDT	Sevin:	carbaryl
Dipterex:	trichlorphon	Sumithion:	fenitrothion
Ekatin:	morphothion	Systox:	demeton
Gammexane:	<i>gamma</i> BHC	Tedion:	tetradifon
Gusathion:	azinphos	Telodrin:	isobenzan
Guthion:	azinphos	Thimet:	phorate
Karathane:	dinocap	Thiodan:	endosulphan
Kelthane:	dicofol	Trithion:	carbophenothion
Korlan:	fenchlorphos	Trolene:	fenchlorphos

### (c) Classification of chemical control measures

Chemicals used for controlling insect pests can be *Insecticides* (intended to kill them), *Chemosterilants* (which cause sterility), *Repellents* (to drive them away) or *Attractants* (to bring them to traps or to poisons).

Orthodox insecticides can be further sub-divided into *Stomach poisons* (which need to be eaten by the insects), *Contact poisons* (which are lethal after contact with the cuticle) and *Fumigants* (which enter by the insect's respiratory system). These categories are not rigid, for several stomach poisons have a slow toxic action on contact; moreover, most contact poisons are lethal on ingestion and some have a fumigant or a repellent action.

## II. CHARACTERISTICS OF SUBSTANCES USED FOR PEST CONTROL

### (a) **Stomach poisons**

#### (i) *Typical uses*

To be effective, stomach poisons must be swallowed by the insects and so they are usually incorporated, in some way, with their food. This presents little difficulty for insects which chew solid foods or lick up exposed liquids. In agriculture and horticulture, stomach poisons are simply applied by spraying or dusting vegetation, to kill leaf-eating caterpillars or beetles. There are, however, obvious difficulties in incorporating insecticides into the food of insects which pierce plants to suck sap or pierce the skin of vertebrates to drink blood. Stomach poisons used in this way are said to have *systemic action*; this method has been quite widely developed in recent years against plant pests, but only to a very limited extent against blood-suckers.

A certain number of pests of public health importance take solid food, which facilitates the use of stomach poisons. Thus poisons in powder form can be used against mosquito larvae, which swallow solid particles. Powder poisons have also been used against cockroaches, which are supposed to swallow them when cleaning their appendages.

In the domestic sphere, impregnation of woollen garments can be used to protect them against clothes moths or carpet beetles, which are killed when they chew the fibres. Again, wood is sometimes impregnated to protect it against boring beetles or (in the tropics) against termites.

Instead of incorporating poison with the insects' staple food, it can be offered in poison bait, which should be specially attractive or else offered in quantity, so that large numbers of the pest feed on it. Poison baits can be moist, solid or liquid. They are not suitable for use in houses against domestic insect pests. Apart from their untidy appearance, the fact that they contain poison potentially harmful to children or domestic animals usually precludes their employment. They may, however, find a limited use against nuisances such as earwigs, crickets, ants or woodlice, which sometimes invade houses from the garden. Another use for poison baits is against houseflies in stables and barns.

#### (ii) *Typical substances*

##### *Inorganic compounds*

The earliest stomach poison insecticides were inorganic chemicals which, as already mentioned, were toxic to higher animals as well as insects, since they are general

protoplasmic poisons. They include metallic salts, such as those of mercury and arsenic, and various fluorine compounds. The heavy metals poison by forming complexes with the sulphhydryl groups of glutathione and cysteine in certain enzymes, while the fluorine compounds affect cell-wall permeability and inhibit enzyme action in unknown ways.

In their use as pesticides, the water solubility of these compounds was an important consideration. Insoluble compounds (e.g. lead or calcium arsenates) were extensively used in agriculture since they could be sprayed on to foliage without rapidly penetrating and damaging the plants or being too easily washed off by rain. Another insoluble compound, the aceto-arsenite of copper, known as Paris Green, was widely used to destroy mosquito larvae, just before the introduction of DDT.

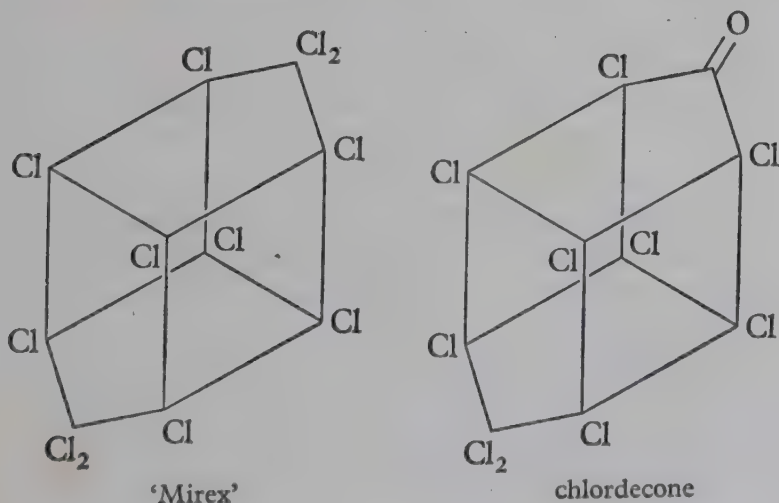
The more soluble compounds include the highly toxic arsenious oxide, mercuric chloride and thallium sulphate; rather less dangerous fluorine compounds such as sodium fluoride or fluosilicate; and still less active borax and boric acid. Most of these have been used in poison baits, though they are seldom employed now, on account of the hazard and because of more effective alternatives.

Some of these substances, especially various fluorine derivatives, were used to impregnate woollen materials for protection against clothes moths. Impregnation of wood against timber pests has also been practised with sodium fluoride, mercuric chloride or borax.

### Organic compounds for poison baits

For circumstances where poison baits are considered desirable, a number of organic compounds, primarily developed for contact action, can be used instead of the older inorganic substances. In particular, the chlorinated cyclodienes and organophosphorus compounds have been used in this way.

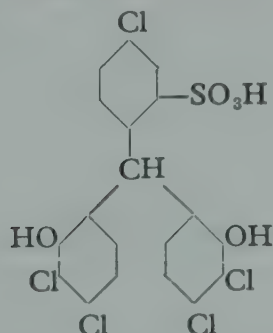
Comparatively few organic compounds are specifically active as stomach poisons. Exceptions are found in the complex chlorinated compounds 'Mirex' and chlordane.<sup>(19)</sup> Though they are related to the chlorinated cyclodiene series, they have little contact action, probably because of their high molecular weight.



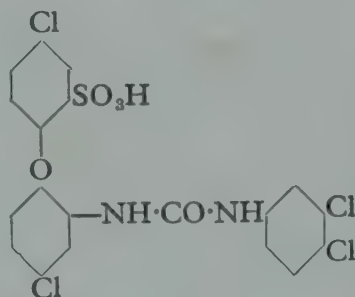
### Organic compounds for moth-proofing<sup>(36, 67)</sup>

The inorganic compounds used to impregnate wool against clothes moth were not only toxic to man but they were not fast to washing, and in later years they were superseded by organic materials, applied in the dye-bath, and firmly fixed to the wool like colourless dyes. These all derive from the original observation of E. Meckbach about 1920, that the dye Martius Yellow imparted resistance to moth attack. A great deal of research by German and Swiss chemists in the next two decades produced some very efficient moth-proofing agents, especially the 'Eulans' of I.G. Farbenindustrie and Mitin of Geigy.

Eulan CN  
(= Lanoc CN of I.C.I.)



Mitin FF



Both these chemicals have a repellent effect and discourage moth larvae from eating treated wool fibres. In addition, they are stomach poisons with distinct toxic action on the grubs. Another interesting approach to moth-proofing is a method of altering the molecular structure of the wool protein, to render it indigestible to moth larvae<sup>(31)</sup> (see pp. 361-362).

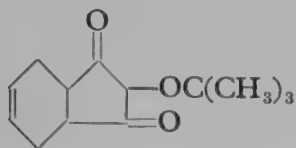
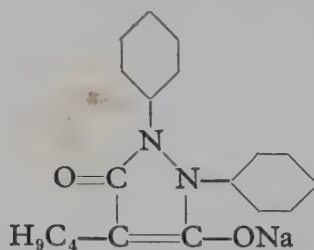
### Organic compounds for systemic action

Toxic chemicals can be given by mouth to animals for protection against various types of pest: bloodsuckers, flies causing cutaneous myiasis, or flies breeding in the dung of treated animals. (This last is not, perhaps, strictly systemic action.) These methods of pest control are at present in the experimental stage; they have not reached the stage where drugs given by mouth can be safely recommended for protecting human beings against biting insects.

The use of chemicals taken by mouth against bloodsuckers began with dosing rabbits with ordinary (contact) poisons, such as DDT, *gamma* BHC or pyrethrins. Limited successes were claimed in killing mosquitoes, bed bugs, lice or ticks fed on the rabbits shortly afterwards.<sup>(44)</sup> The effective doses, however, were rather close to those dangerous to the rabbits. Later research revealed certain less familiar chemicals as more suitable for this particular use; notably certain indandione derivatives and phenylbutazone.<sup>(41, 52)</sup> Certain organo-phosphorus compounds tested for this use showed some action at safe doses, but were less promising than phenylbutazone.<sup>(18)</sup>

The use against flies causing skin myiasis (warble flies, cattle grubs) is restricted to veterinary uses, but may be mentioned here for interest. The insecticides are

2-pyvalyl 1,3-indandione

phenylbutazone (B.P.)  
(mono-sodium 4-butyl-1,2-diphenyl-3,5-pyrazolidinedione)

given to cattle as a single drench, or added to the diet or drinking water, injected or merely poured over the skin. In any case, they are absorbed and kill the cattle grubs without harming the beasts. Suitable materials are organo-phosphorus compounds which are detoxified in mammalian tissue faster than in insects, e.g. coumaphos, fenclorophos and dimethoate.

## (b) Contact poisons

### (i) Typical uses

There has been an increasingly sharp dichotomy in the uses of contact insecticides, according to whether an immediate kill is required, or whether the emphasis is on long continued insecticidal action.

To accomplish a rapid 'knock-down' and kill, the insecticide is dispersed as a fine spray or, for flying insects, as an air-borne mist, aerosol or smoke. This follows in the tradition of the domestic fly spray, intended to give immediate, though perhaps only temporary, relief from the nuisance. The hand atomizing sprayers used with domestic fly sprays have been largely superseded by liquefied gas aerosol dispensers. An important public health use of these is for the disinsection of aircraft, to prevent the dissemination of mosquitoes (especially infected ones) from country to country. Large aerosol or smoke generators have been employed for the treatment of large buildings or outdoor areas, to secure temporary relief from various unpleasant or noxious insects; but this is expensive and perhaps only justified in special circumstances.

Rudiments of the alternative objective of prolonged insecticidal action are found in the long-established use of powder insecticides. In dusting a dog for fleas or blowing insecticide powder into crevices to kill cockroaches, one expected some continuing insecticidal effect from the residues. The exceptional importance of 'residual action', however, was not apparent until the introduction of DDT and other persistent synthetic contact poisons. When these are applied to walls etc. of dwellings, a wide range of domestic pests can be attacked; these include any insects likely to alight on or crawl over the treated surfaces (e.g. houseflies, mosquitoes, cockroaches, bed bugs, ants).

Surface treatments or impregnation of various articles can give lasting protection from other pests: for examples, the treatment of undergarments against body lice, of woollen materials against clothes moths or of furniture against timber pests.

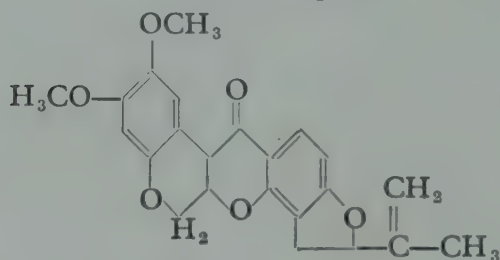
(ii) *Typical substances**Substances of vegetable origin*

*Miscellaneous substances of minor importance.* Various plant products have been used as insecticides, but nearly all have been displaced by modern synthetic compounds.

Among the alkaloids, the best known is nicotine from tobacco, which has been widely used in horticulture. Anabasine is a similar alkaloid, from the plant *Anabasis aphylla* which grows wild over large parts of Asia; and this is used to some extent in the U.S.S.R. A mixture of alkaloids known as the veratrine group is obtained from the rhizomes of *Veratrum album* ('hellebore') or from the seeds of *Sabadilla officinale* ('sabadilla'), both liliaceous plants; but they are little used.

*Rotenone and allied compounds.* Another type of insecticide from plants comprises rotenone and allied compounds. These are the active ingredients of plants used as fish poisons by the natives of various tropical countries. They have been mainly extracted from the roots of *Derris* spp. ('derris' or 'tuba root') in Malaya or from *Lonchocarpus* spp. ('cube' or 'timbo') in South America. These plants belong to the Leguminosae, which includes other rotenone-bearing genera, such as *Tephrosia*, *Lonchocarpus* and *Millettia*. Rotenone, like the other active compounds (toxicarol, deguelin, elliptone and sumatrol, etc.), is a white crystalline material, very insoluble in water or mineral oils, but dissolving in ether, chloroform and some vegetable oils. These compounds are toxic to insects and acarines by contact (and also as stomach poisons) but the speed of action is rather slow. In oil solution, they are moderately toxic to mammals, though the dry powders are not dangerous.

Rotenone  
M.P. 163°C



*Pyrethrum.* Pyrethrum insecticides are obtained from the flowerheads of *Chrysanthemum cinerariifolium*. Formerly this was mainly grown in the Balkans and the insecticide derived from the powdered flowers was known as Dalmatian Insect Powder; but since 1920 it has been extensively grown in Japan and from 1933 large quantities have been exported from Kenya.

The active principle of pyrethrum is an oily liquid, which occurs to the extent of about 1% by weight of the dried flower-heads. This liquid, which is insoluble in water but dissolves in various organic solvents, contains several related compounds of varying degrees of insecticidal potency. They are difficult to extract pure owing to the presence of resinous impurities which are difficult to separate from them. The active constituents are complex and their identification resulted from

the outstanding work of the Swiss chemists Staudinger and Ruzicka in the 1920s. They comprise esters of chrysanthemum mono- and di-carboxylic acid. These are combined with alcoholic ketone groups known as pyrethrolone and cinerolone to give pyrethrins and cinerins, respectively. The pyrethrins and cinerins are designated 'I' or 'II' according to whether the mono- or di-carboxylic acid is involved. The main active constituents of pyrethrum, then, are pyrethrins I and II and cinerins I and II (see Table 5). For practical purposes they are sometimes grouped together as 'total pyrethrins'. The matter is further complicated by the fact that both the acid and the keto-alcohol portions of these compounds can exhibit steric as well as geometric isomerism. This is important in regard to the synthetic preparation of compounds homologous with the pyrethrins and cinerins (see p. 101). The natural compounds, which are formed from *d-trans*-acids and *d-cis*-keto alcohols are more active than the racemic mixtures resulting from synthesis.<sup>(59)</sup>

Pyrethrins and cinerins are rather unstable chemically, owing to oxidation, which occurs rapidly on exposure to sunlight. For this reason, residual films do not retain their potency for more than a few days. Even in bulk, it is desirable to keep pyrethrum preparations in darkness, with a trace of anti-oxidant.

The insecticidal effects of the pyrethrum constituents are extremely rapid and they have been widely used on account of their remarkable 'knock-down' effect, which is due to a rapid paralysis induced in contaminated insects. On the other hand, their effect is not always lethal, so that insects may recover from light doses causing temporary paralysis.

In regard to biological activity, the pyrethrins are more insecticidal than the cinerins. The 'II' compounds are more rapid in action than the 'I' forms; but there is some uncertainty about the relative insecticidal potency of the two types. All these compounds are comparatively innocuous to vertebrates, which makes them valuable for use against insects of medical or domestic importance.

*Synergists.*<sup>(16, 32, 39, 50)</sup> A disadvantage of pyrethrum is the unreliable kill obtained with low concentrations and the relatively high cost of strong preparations. This difficulty can be largely overcome by the addition of potentiating compounds, usually known as synergists. Most of them have little or no insecticidal action alone, but when mixed with pyrethrum preparations, they greatly augment their insecticidal powers. Probably they act by suppressing detoxication mechanisms in the insect's tissues.

The first effective pyrethrum synergist 'IN930' (N-iso-butyl-undecyleneamide) was reported in 1938. Shortly afterwards it was discovered that sesame oil synergized pyrethrum. The main active ingredient of the oil was found to be sesamin; and subsequent tests of analogous compounds showed that the essential characteristic of the molecule was a methylene dioxyphenyl group. Many compounds including this group in their molecules have been synthesized and some have shown good synergizing powers. They are mostly pale amber-coloured liquids, insoluble in water, moderately soluble in oils and miscible with organic solvents. They are generally of low mammalian toxicity. They include: 'Bucarpolate', *n*-propyl isome, safroxan, sesoxane and sulphoxide. One of the best, and most widely used, is piperonyl butoxide discovered about 1947.



Both the organic thiocyanates and thiocyanoacetate contact poisons are oily liquids, insoluble in water but miscible with oils and organic solvents.

*Synthetic pyrethroids.*<sup>(6, 13, 59)</sup> The extensive research on structure and biological activity of pyrethrum components and analogous compounds eventually led to the production of some synthetic pyrethroids. The most satisfactory comprise: allethrin (1949), furethrin (1952), cyclethrin (1954), barthrin (1958) and dimethrin (1959). Their structural formulae are shown in Table 5. It will be seen that they are all based on synthetic mono-carboxylic acid combined with variations of the keto-alcohol group.

The insecticidal and other properties of the synthetic pyrethroids resemble those of the natural compounds, though they are generally less active. Allethrin is not

TABLE 5 *Structural formulae of natural and synthetic pyrethroids*

$  \begin{array}{c}  \text{H}_3\text{C}\cdot\text{C} \\    \\  \text{CH}-\text{CHCOOCH} \\    \quad \quad   \\  \text{R}_1\text{HC} \quad \quad \text{C}(\text{CH}_3)-\text{CR}_2 \\  \quad \quad \quad   \\  \quad \quad \quad \text{CH}_2-\text{CO}  \end{array}  \quad \text{or} \quad  \begin{array}{c}  \text{H}_3\text{C}\cdot\text{C} \\    \\  \text{CHCOOR}_3 \\    \\  \text{R}_1\text{HC}  \end{array}  $		
Name	R <sub>1</sub>	R <sub>2</sub>
Pyrethrin II	CH <sub>3</sub> OOC·C(CH <sub>3</sub> ):CH—	—CH <sub>2</sub> CH:CH·CH:CH <sub>2</sub>
Cinerin II	ditto	—CH <sub>2</sub> CH:CH·CH <sub>3</sub>
Pyrethrin I	·CH <sub>2</sub> CH:CHCH:CH <sub>2</sub> —	—CH <sub>2</sub> CH:CH·CH:CH <sub>2</sub>
Cinerin I	ditto	—CH <sub>2</sub> CH:CH·CH <sub>3</sub>
Allethrin	ditto	—CH <sub>2</sub> ·CH:CH <sub>2</sub> —
Furethrin	ditto	$  \begin{array}{c}  -\text{CH}\cdot\text{C}:\text{CH} \\    \quad \quad \diagup \\  \text{O}-\text{CH} \quad \text{CH}  \end{array}  $
Cyclethrin	ditto	$  \begin{array}{c}  -\text{CH}-\text{CH} \\    \quad \quad \diagup \\  \text{CH}_2-\text{CH}_2 \quad \text{CH}  \end{array}  $
R <sub>3</sub>		
Barthrin	ditto	$  \begin{array}{c}  -\text{CH}_3 \\    \\  \text{Cl} \quad \text{C}_6\text{H}_2 \quad \text{O} \quad \text{CH}_2 \\  \quad \quad \quad \diagdown \quad \diagup \\  \quad \quad \quad \text{O}  \end{array}  $
Dimethrin	ditto	$  \begin{array}{c}  -\text{CH}_2-\text{C}_6\text{H}_3-\text{CH}_3 \\    \\  \text{H}_3\text{C}  \end{array}  $

only the oldest, but also one of the most potent, being as good as or better than natural pyrethrins to houseflies, though generally less toxic to other insects. As already mentioned (p. 99), the particular isomeric form of the natural pyrethrins and cinerins (*d-trans*-acid plus *d-cis*-keto-alcohol) is about the most effective, so that the synthetic compounds (being *d,l-cis-trans* mixtures) tend to be less active. Furthermore, the synergists (p. 99) are not so effective in potentiating the synthetic compounds as the natural ones.

In practice, only allethrin among the synthetic pyrethroids is produced on a large scale. Its manufacture seems to be restricted to the United States, where synthetic substances are favoured by government policy in relation to self-sufficiency (in case of war, etc.). It is true that the present price of commercial grade allethrin is only about two-thirds that of the active principles of pyrethrum concentrate. However, this does not compensate for the greater concentrations needed to compete with synergized pyrethrins against flies or unsynergized pyrethrins for other insects. On a strict cost basis, then, the synthetic material does not quite compete with the natural one; though there may be minor advantages in freedom from traces of resinous impurities.

*DDT and analogous compounds.*<sup>(48)</sup> The insecticidal properties of DDT were discovered by the Geigy Company in Switzerland, in 1939. Its subsequent unprecedented achievements were due to a novel combination of the following properties: it is toxic to virtually all insects, while being relatively harmless and unobjectionable to mammals; it is fairly easy to manufacture and, being chemically and physically stable, it can give prolonged residual insecticidal action. While DDT was only the first of a long series of new synthetic contact insecticides, it is still one of the most satisfactory in several respects and it continues to be very widely used. Thus, over 80,000 tons were produced in U.S.A. alone in 1962.

The abbreviation 'DDT' is taken from the initials of the generic chemical name Dichloro Diphenyl Trichlorethane, the most active type of which is the *pp'* isomer shown in Fig. 10. A considerable number of analogous compounds shows similar insecticidal powers, but none of these equals DDT in overall potency. Only a very few have been produced commercially (e.g. DDD, methoxychlor, 'Dilan'; see Fig. 10) and these on a much smaller scale for special circumstances. Thus, DDD and methoxychlor tend to be used in cases where their exceptionally low mammalian toxicity (see Table 7) is an advantage. 'Dilan' may be used with some success against DDT-resistant insects.

*pp'*-DDT is a white crystalline solid (M.P. 109–110°C; B.P. 185°/1 mm; *d* 1.56; V.P.  $1.5 \times 10^{-7}$  mm Hg at 20°C). With extremely low solubility in water, it dissolves easily in many aromatic organic solvents and to some extent in mineral oils. Chemically stable under normal conditions, it is decomposed by alcoholic alkali and to some extent by traces of metallic salts. Technical DDT contains related compounds, especially the *o-p* isomer.

*pp'*-DDD (M.P. 109°C; *d* 1.385).

Methoxychlor (M.P. 78°C; *d* 1.41).

'Dilan' (a plastic mixture of nitropropane-DDT and nitrobutane-DDT: Prolan, M.P. 81°C and Bulan, M.P. 67°C, respectively).

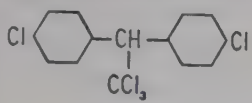
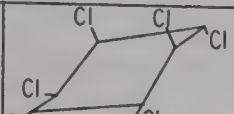
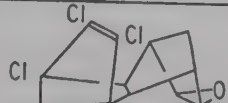
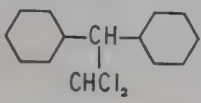
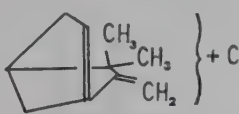
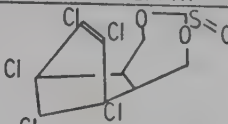
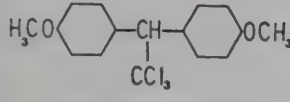
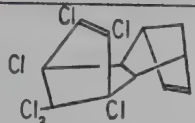
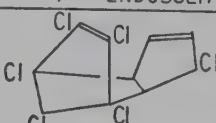
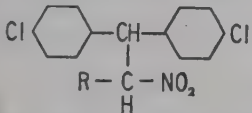
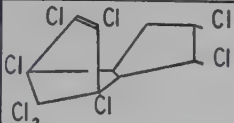
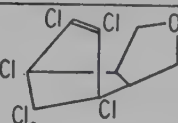
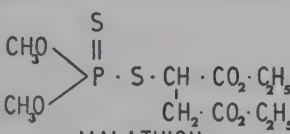
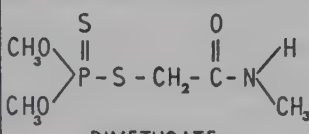
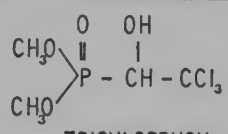
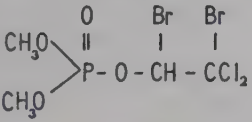
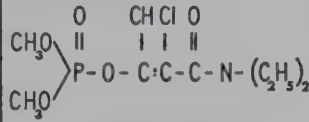
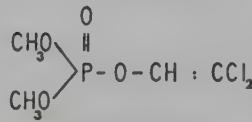
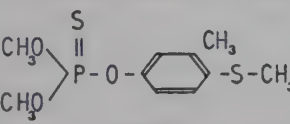
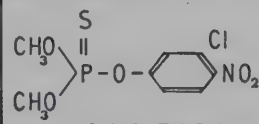
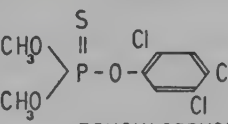
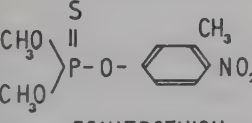
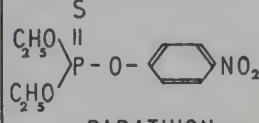
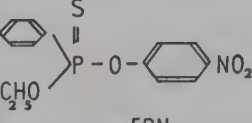
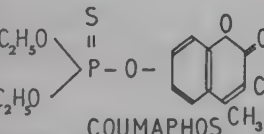
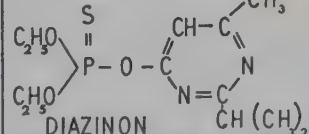
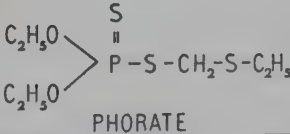
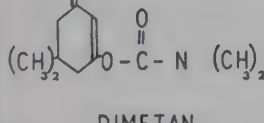
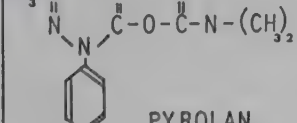
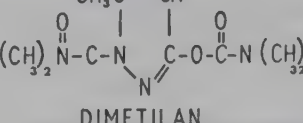
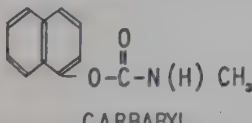
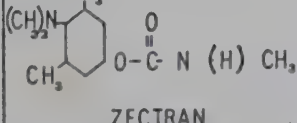
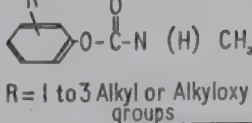
 <p>DDT</p>	 <p>gamma BHC</p>	 <p>DIELDRIN</p>
 <p>DDD</p>	 <p>TOXAPHENE ETC</p>	 <p><math>\beta</math> - ENDOSULFAN</p>
 <p>METHOXYCHLOR</p>	 <p>ALDRIN</p>	 <p>HEPTACHLOR</p>
 <p>PROLAN(R=CH<sub>3</sub>) BULAN(R=CH<sub>2</sub>CH<sub>3</sub>)</p>	 <p><math>\beta</math> - CHLORDANE</p>	 <p>ISOBENZAN</p>
 <p>MALATHION</p>	 <p>DIMETHOATE</p>	 <p>TRICHLORPHON</p>
 <p>NALED</p>	 <p>PHOSPHAMIDON</p>	 <p>DICHLORVOS</p>
 <p>FENTHION</p>	 <p>CHLORTHION</p>	 <p>FENCHLORPHOS</p>
 <p>FENITROTHION</p>	 <p>PARATHION</p>	 <p>EPN</p>
 <p>COUMAPHOS</p>	 <p>DIAZINON</p>	 <p>PHORATE</p>
 <p>DIMETAN</p>	 <p>PYROLAN</p>	 <p>DIMETILAN</p>
 <p>CARBARYL</p>	 <p>ZECTRAN</p>	 <p>R = 1 to 3 Alkyl or Alkyl oxy groups</p>

FIG. 10. Structural formulae of some new synthetic contact insecticides.

The toxic action of DDT and its analogues specifically affects sensory nerves, the excitability of which is greatly facilitated. Insects are more easily affected than mammals and birds, largely because the DDT penetrates their cuticles with ease but does not readily get through the skin of mammals or birds. Intoxicated insects show characteristic signs of tremors and incoordinated movements, which go on continuously almost to the point of death, which is sometimes long delayed.

*gamma* BHC. 'BHC' stands for benzene hexachloride, though this is a misnomer, since the compound in question is actually hexachlor cyclohexane; and in Europe the abbreviation HCH is used. This chemical exists in a number of steric isomers, differing in the orientation of the chlorine atoms in the molecule. They are designated  $\alpha$ ,  $\beta$ ,  $\gamma$ ,  $\zeta$ ,  $\epsilon$ , etc., and it was discovered in Britain about 20 years ago that only one of them, the *gamma* isomer, is highly insecticidal. The unique potency of *gamma* BHC is remarkable, since some scores of other polyhalogenated cyclohexanes have been synthesized, but none was found highly insecticidal. This contrasts with other types of synthetic contact poisons, in which changes in the molecule do not always obliterate the activity.

Pure *gamma* BHC is a white crystalline solid (M.P. 112–113°C;  $d$  1.85; V.P.  $9.4 \times 10^{-6}$  at 20°C), with solubilities not unlike those of DDT. Like DDT, too, it is chemically stable under ordinary conditions. It has a distinctive, rather musty odour, which is considerably stronger and unpleasant in crude samples.

*gamma* BHC is toxic to virtually all arthropods and very much less so to vertebrates. Its toxic action, which is distinctly more rapid than that of DDT, is not well understood, but appears to involve the central nervous system.

Generally speaking, *gamma* BHC is several times as insecticidal as DDT and for immediate contact action it is used at a fifth to a tenth the concentration. Having a distinctly higher vapour pressure, its residual effect is considerably shorter than that of DDT (or dieldrin). However, the vapour has a useful short-range fumigant effect in some circumstances (e.g. insects may be killed by residues absorbed into porous surfaces).

*Chlorinated cyclodiene insecticides.*<sup>(48)</sup> These are highly chlorinated cyclic hydrocarbons with a characteristic 'endo methylene bridge'. Alternatively, the essential nucleus of the molecule can be visualized as being formed of two bent pentagons having three points in common. There are two distinct types: the semi-synthetic mixtures produced by chlorinating pine oil and the synthetic compounds made by Diels–Alder condensation.

It has been known for some years that chlorination of the terpenes in pine oil increased their insecticidal powers. As early as 1942, the Russians were using 'Substance SK', subsequently identified as chlorinated camphene. Insecticides of this type have been developed in other countries, the best-known examples being Toxaphene (U.S.A., 1947) and Strobane (U.S.A., 1953). Both are waxy aromatic materials containing mixtures of compounds averaging 66 to 69% Cl; virtually insoluble in water, they readily dissolve in organic solvents, especially aromatic ones. The general structure of these chlorinated compounds resembles that of the synthetic cyclodiene (see Fig. 10). Their mode of action appears to be similar and they are involved in the same resistance group.

The synthetic cyclodiene insecticides have been mainly developed in the U.S.A., since 1945. They are produced by Diels–Alder molecular condensation; i.e. a fusion of two 5-membered rings. They include the following compounds (whose structural formulae are shown in Fig. 10):

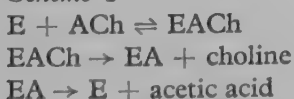
aldrin	(M.P. 104°C; $d$ 1.65; V.P. $6 \times 10^{-6}$ mm at 25°C)
chlordane	(viscous liquid mixtures of $\alpha$ (M.P. 103°C) and $\beta$ (M.P. 105°C); $d$ 1.60; V.P. $1 \times 10^{-5}$ mm at 25°C)
dieldrin	(M.P. 176°C; $d$ 1.75; V.P. $1.8 \times 10^{-7}$ mm at 25°C)
endosulphan	(a mixture of $\alpha$ (M.P. 109°C) and $\beta$ (M.P. 209°C))
endrin	(M.P. 245°C; $d$ 1.81; V.P. $2 \times 10^{-7}$ mm at 25°C)
heptachlor	(M.P. 103°C; $d$ 1.58; V.P. $3 \times 10^{-4}$ mm at 25°C)
isobenzan	(M.P. 122°C; $d$ 1.87; V.P. $3 \times 10^{-6}$ mm at 20°C)

These compounds have the same general solubility pattern, being very insoluble in water ( $<0.1$  ppm), slightly soluble ( $<5\%$ ) in alcohol or odourless kerosene and readily soluble (25–50%) in aromatic solvents. They are all widely toxic to insects, some being very potent indeed. Unfortunately, their mammalian toxicity also tends to be moderately high. Their mode of action is obscure, but is known to involve the central nervous system.

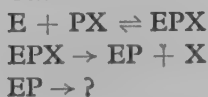
*Organo-phosphorus insecticides.*<sup>(54)</sup> The introduction of this type of insecticide originates largely from the pioneer work of G. Schrader in Germany, beginning about 1934. Following the publication of his work in 1947, thousands of different organic phosphorus compounds were synthesized and tested and a considerable number is in commercial production. The first examples in wide use (e.g. parathion, TEPP) were dangerously poisonous to higher animals, but later safer compounds were found; finally the trend of research has been to seek high insecticidal potency in combination with low mammalian toxicity.

The relevant structure of the organo-phosphorus insecticides can be understood better in relation to their mode of action, which concerns the enzyme acetylcholinesterase. In normal nervous activity, the chemical acetylcholine is rapidly secreted in small amounts at vital points in the system, especially the nerve junctions or synapses. The stimulating effect of traces of this chemical causes transmission of a nerve impulse; but too much would cause chaos and the excess is rapidly destroyed by the enzyme. This is done by temporary union of acetylcholine with the enzyme, followed by its degradation and elimination of the waste products, leaving the enzyme unchanged (as in Scheme I, below). The organic phosphorus esters, however, also can react with the enzyme; but in this case, the final break-up occurs very slowly, so that the enzyme remains blocked or poisoned and ACh accumulates (Scheme II).

*Scheme I*

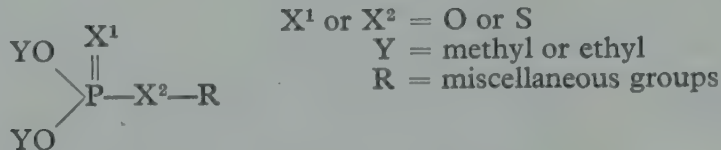


*Scheme II*



where E = enzyme; ACh = acetylcholine; P = (Alk. O)<sub>2</sub> P(O)—; X = miscellaneous groups.

There are, in fact, several basic types of organo-phosphorus ester which can cause this type of poisoning; but the majority of satisfactory insecticides conform to the following pattern:



The activity of the whole molecule is regulated by changes in X, Y or R.

The active anti-cholinesterase agents have  $\text{X}^1 = \text{O}$ ; but in animal tissue  $\text{P} = \text{S}$  can be oxidized to  $\text{P} = \text{O}$ , thus greatly increasing the insecticidal potency. Accordingly, insecticidal compounds may have either oxygen or sulphur in this position. As regards Y, steric considerations restrict the more effective compounds to those with methyl or ethyl radicles (though in EPN, the whole alkyloxy group is replaced by phenyl).

A great variety of groups can be introduced at R. They affect the overall physical nature of the molecule; they can affect the reactivity of the phosphorus atom (through electron induction effects); finally, they may be important sterically.

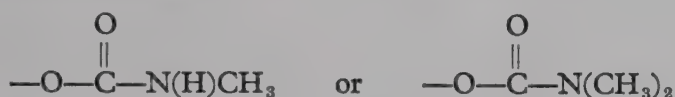
This briefly summarizes the factors affecting potency. Other factors concerned with detoxication are also important, especially in regard to selective toxicity (insects as opposed to mammals). Thus, animal tissues contain a range of enzymes which may be able to detoxify organo-phosphorus compounds. Certain phosphatases can attack them at different points in the molecule, rendering it harmless. In consequence, the outcome of contamination of an insect or higher animal with a potentially toxic organo-phosphorus compound will be the outcome of various physical processes of penetration and distribution within the body and of chemical processes of toxication and detoxication. If insects differ in some of these processes from higher animals, it should be possible to take advantage of this and choose compounds destroyed in the mammal but not in the insect. Some progress in this direction has been made.

In physical properties, the organo-phosphorus insecticides are usually liquids, soluble in some organic solvents but rarely so in petroleum oils; sometimes sparingly soluble in water. The performance as residual insecticides of some well-known examples is somewhat curtailed by a rather higher volatility than that of the chlorinated compounds. Examples of vapour pressures are as follows: malathion,  $4 \times 10^{-5}$  at  $30^\circ\text{C}$ ; parathion,  $6 \times 10^{-4}$  at  $24^\circ\text{C}$ ; diazinon,  $1.4 \times 10^{-4}$  at  $20^\circ\text{C}$ ; fenthion,  $2 \times 10^{-6}$  at  $20^\circ\text{C}$  (all mm of Hg). Nearly all have disagreeable odours, partly due to impurities.

*Carbamate insecticides.*<sup>(48)</sup> It has been known, for many years, that various carbamic acid esters are toxic to animals; but these active compounds were water-soluble and not suitable as insecticides. From about 1947, however, the Swiss firm Geigy began a search for suitable contact insecticides of this type, which resulted in the commercial production of one or two compounds (Dimetan, Pyrolan, Isolan). Subsequently a variety of insecticidal carbamates have been developed in various countries.

The mode of action of the carbamate poisons resembles that of the organo-phosphorus compounds, in that both attack the enzyme acetylcholinesterase. The signs of poisoning are likely to be similar in both mammals and insects, since both derive from excess of acetylcholine. There are, however, differences. The organo-phosphorus compounds actually combine with the enzyme, which becomes phosphorylated at one point. In contrast, the active carbamates possess steric resemblance to acetylcholine and compete with it for fixation at two sites on the enzyme. Once *in situ*, they are less easily hydrolysed than the natural substrate and thus block the enzyme. On the other hand, the inhibition is not so irreversible as that caused by the more potent organo-phosphorus poisons.

For steric reasons, the most active carbamates are based on the *N*-methyl or *N,N*-dimethyl forms of the acid:



Considerable variation in the alcoholic portion of the molecule is possible; it may consist of a phenol, pyrazolol or other heterocyclic alcohol; but steric considerations affect the nature and position of substituents to some extent. For optimum contact insecticidal effect, the whole molecule must be non-polar and lipoid-soluble to allow penetration of the cuticle. Examples are given in Fig. 10. Also, arprocarb; 2-isopropoxyphenyl *N*-methylcarbamate, and aminocarb; 3-methyl-4-dimethylaminophenyl *N*-methylcarbamate.

### (c) Contact poisons for mites and ticks: Acaricides

The Acarina are sufficiently distinct from the Insecta to require some rather different types of poison to control them. Possibly this reflects a difference in the cuticle, which governs the entry of contact poisons.

#### (i) Typical uses

Many different mites are troublesome agricultural and horticultural pests and still others are harmful to stored food. Ticks are mainly a veterinary problem. Comparatively few acarines are pests of domestic or public health importance in Britain. Probably the most important is *Sarcoptes scabiei*, the itch mite, to control which medicaments are applied to the human body. Allied to it are the mites causing mange in domestic animals.

Poultry keepers may suffer from the bloodsucking poultry mite, *Dermanyssus gallinae*, which also invades houses from wild bird nests. This may be attacked by spraying the infested chicken houses or bird nests. Apart from this, a few nuisance mites (e.g. the clover mite) may require the spraying of acaricide to walls of infested houses.

#### (ii) Typical substances<sup>(48)</sup>

Among the accepted insecticides, several organo-phosphorus compounds are effective acaricides (e.g. malathion, diazinon, parathion, dimethoate, phosphamidon). The carbamate carbaryl, too, is a good acaricide. Of the chlorinated hydrocarbons, *gamma* BHC is fairly effective against mites and ticks. DDT, however, is

virtually innocuous to most mites and many ticks, though these can be killed by analogous compounds, which are useless as insecticides. Thus, a range of acaricides are built on the pattern phenyl-X-phenyl, but only some are analogous to DDT. Though di-*para*-chlorine substitution of the phenyls is common, it is not essential and the bridge structure is not necessarily on an ethane plan.

<i>Acaricide</i>	<i>Phenyl substituents</i>	<i>Bridge</i>
benzyl benzoate	nil	—CH <sub>2</sub> OC(O)—
DMC; 'dimite'	<i>p</i> Cl <i>p</i> Cl	—C(OH)—   CH <sub>3</sub>
dicofol	<i>p</i> Cl <i>p</i> Cl	—C(OH)—   CCl <sub>3</sub>
chlorobenzilate	<i>p</i> Cl <i>p</i> Cl	—C(OH)—   CO <sub>2</sub> C <sub>2</sub> H <sub>5</sub>
chlorbenside	<i>p</i> Cl <i>p</i> Cl	—CH <sub>2</sub> S—
fluorbenside	<i>p</i> Cl <i>p</i> F	—CH <sub>2</sub> S—
fensone	<i>p</i> Cl	—O—S(O <sub>2</sub> )—
chlorfensone	<i>p</i> Cl <i>p</i> Cl	—O—S(O <sub>2</sub> )—

There are, of course, other acaricides. One that may be mentioned is tetraethyl thiuram disulphide: (C<sub>2</sub>H<sub>5</sub>)<sub>2</sub>NC(S)SS(S)CN(C<sub>2</sub>H<sub>5</sub>)<sub>2</sub>. Another is aramite: (CH<sub>3</sub>)<sub>3</sub>C(C<sub>6</sub>H<sub>4</sub>)OCH<sub>2</sub>CH(CH<sub>3</sub>)OS(O)O(CH<sub>2</sub>)<sub>2</sub>Cl.

#### (d) Fumigants

##### (i) Typical uses

Fumigants can secure the most rapid eradication of pests from a limited space. They do not normally leave residues, however, so that they give no protection from reinfestation; and this seriously handicaps them (in comparison with residual contact insecticides) for most uses in public health entomology. Added to this is the fact that most of the more efficient fumigants are dangerously toxic to mammals. Accordingly, while fumigants still offer useful service in the disinfection of bulk food and other stored products, their use against insects of public health importance has greatly diminished. Thus hydrogen cyanide was formerly used to fumigate human dwellings against bed bugs and similar pests. This was a troublesome procedure and potentially dangerous, so that an Act of Parliament was passed to regulate the operation. With the advent of synthetic contact insecticides, this type of fumigation has virtually ceased.

Hydrogen cyanide and methyl bromide still find a limited use in fumigating furniture and bedding against bed bugs, clothes moths etc. in specially constructed steel vans.<sup>(12)</sup> On a smaller scale, various organic liquid fumigants can be used to disinfect verminous clothing in boxes, bins or plastic sacks.<sup>(15a)</sup>

Domestic uses of fumigants comprise the injection of woodwork against furniture beetle (*ortho*-dichlorobenzene) and the use of solid fumigants (naphthalene, etc.) against clothes moths.

Perhaps the only interesting modern development is the introduction of the 'residual fumigant'. This is an insecticide of low volatility but high insecticidal

potency, e.g. dichlorvos (see Fig. 10 and Table 6). Containers which gradually emit the vapour are hung up in human dwellings. With restricted ventilation, enough vapour may be present to kill sensitive insects, like mosquitoes, while being harmless to man.

(ii) Typical substances<sup>(51, 55)</sup>

Gaseous fumigants

Substances gaseous at normal temperatures must have low molecular weight and this limits the number available. Many true gases are inorganic compounds, some being rather inert, others very reactive and perhaps corrosive. Comparatively few successful fumigants have a boiling point below or near to ordinary room tempera-

TABLE 6 Properties of fumigants

Group	Name and formula	Boil- ing point (°C)	Vapour pressure at 20°C (mm Hg)	Saturation at 20°C (mg/litre)	Vapour density (air = 1)	Acute toxicity to mammals	Inflamma- bility
	Phosphine PH <sub>3</sub>	-125	>760	—		× × ×	× × ×
	Sulphuryl fluoride SO <sub>2</sub> F <sub>2</sub>	-55	>760	—		×	0
I	Methyl bromide CH <sub>3</sub> Br	3.5	>760	—	3.3	× × ×	0
	Ethylene oxide (CH <sub>2</sub> ) <sub>2</sub> O	11	>760	—	1.5	×	× × ×
	Hydrogen cyanide HCN	26	612	905	0.9	× × ×	×
	Ethyl formate H·COOC <sub>2</sub> H <sub>5</sub>	54	196	837	0.92	×	× ×
II	Methallyl chloride CH <sub>2</sub> :C(CH <sub>3</sub> )CH <sub>2</sub> Cl	72	102	505	3.1	× ×	0
	Ethylene dichloride CH <sub>2</sub> ClCH <sub>2</sub> Cl	84	63	345	3.4	×	×
	Ethylene dibromide CH <sub>2</sub> BrCH <sub>2</sub> Br	131	11	112	6.5	×	0
	<i>o</i> -Dichlor-benzene <i>o</i> -C <sub>6</sub> H <sub>4</sub> Cl <sub>2</sub>	179	1.2	9.3	—	0	0
III	<i>p</i> -Dichlorobenzene <i>p</i> -C <sub>6</sub> H <sub>4</sub> Cl <sub>2</sub>	—	0.64	4.9	—	0	0
	Naphthalene C <sub>10</sub> H <sub>8</sub>	—	0.08	0.6	—	0	0
	Dichlorvos C <sub>4</sub> H <sub>7</sub> PO <sub>4</sub> Cl <sub>2</sub>	—	0.15	1.8	—	0	0

tures; some of them are shown in Group I of Table 6. Most of them can be dispensed from metal cylinders, sometimes with additional heat to assist volatilization. Hydrogen cyanide and phosphine can be generated chemically, *in situ*. In general, all this group are rather difficult and dangerous to handle without special training.

Phosphine (generated from small aluminium phosphide-ammonium carbonate tablets) and ethylene oxide are mainly used for grain fumigation. Sulphuryl fluoride, a new fumigant, has been employed against termites in the U.S.A. Hydrogen cyanide and methyl bromide have been used in furniture fumigation (pp. 136-137). Methyl bromide has the advantage that its residues can be more easily removed by airing; but it causes an unpleasant taint with some materials.<sup>(12)</sup>

### *Vapour fumigants*

The fumigants in Groups II and III of Table 6 are vapours in equilibrium with liquids or solids at room temperature. For each compound, there is a saturation concentration dependent on its vapour pressure and molecular weight and the temperature, thus:

$$C = \frac{P}{760} \times \frac{273}{T} \times \frac{M}{22.4} \times 1000 = \frac{16 M.P}{T}$$

$C$  = saturation concentration (mgm/litre)

$P$  = vapour pressure (mm Hg)

$M$  = molecular weight (gm)

$T$  = absolute temperature

If excess of the compound is put into a closed space, the vapour will theoretically reach the saturation concentration; but, in practice, it is seldom attained, because of leakage and absorption.

The compounds in Group II are relatively safe to handle on a small scale, for box or bin fumigation. Carbon disulphide (B.P. 46°C; sat. conc. 20°C, 1250 mg/l) has been omitted, because it is not only highly inflammable, but stinks horribly. The other compounds are not objectionable, but all are slightly toxic to man and should not be inhaled excessively. Carbon disulphide is also highly inflammable.

The fumigants in Group III are virtually safe for normal handling.

### (e) Chemosterilants

The theoretical advantages of sterilizing insects, rather than killing them, is that if the males can be sterilized without affecting their vigour, they will seek out normal females and by mating with them, discourage their union with normal males. Thus the insects are employed in their own extermination and this subject is discussed under the heading of biological control.

This section deals specifically with chemicals which induce sterility. Radioactive sterilization is dealt with elsewhere (p. 88).

#### (i) Typical uses

Chemosterilants can be employed in two general ways against insects.

Firstly, they can be used under controlled conditions, to sterilize large numbers

of insects from an artificial colony to produce sterile males for release. This is merely an alternative to radioactive sterilization, but it has some advantages of cheapness and convenience.

Alternatively, for insects which either cannot be reared in vast numbers or are too objectionable to release in quantity, chemosterilants can be exposed in baits to the wild insect population. Since many of these compounds are dangerous to other animals, their use in baits requires careful consideration and precautions. So far, they have been used with some success and safety in isolated refuse tips, against houseflies.

(ii) *Typical substances*<sup>(7, 62)</sup>

Chemosterilants work by an attack on active cell nuclei, i.e. on rapidly dividing cells as in the genitalia. Similar compounds have been used to inhibit malignant growths in man and some of the drugs used in cancer therapy provided an early source of chemosterilants for insects. Two types of compound have been tried: anti-metabolites and alkylating agents, the latter being most successful.

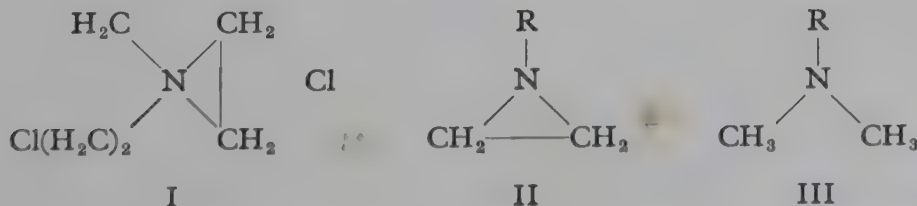
*Anti-metabolites*

During cell proliferation, there is continual synthesis of nucleic acid; this can be inhibited by certain anti-metabolites which antagonize the synthesis of purines and pyrimidines or prevent their incorporation into nucleic acid (e.g. methotrexate, aminopterin). Insects given small doses of these are prevented from developing normal eggs or sperms. If both sexes are dosed, sterility ensues.

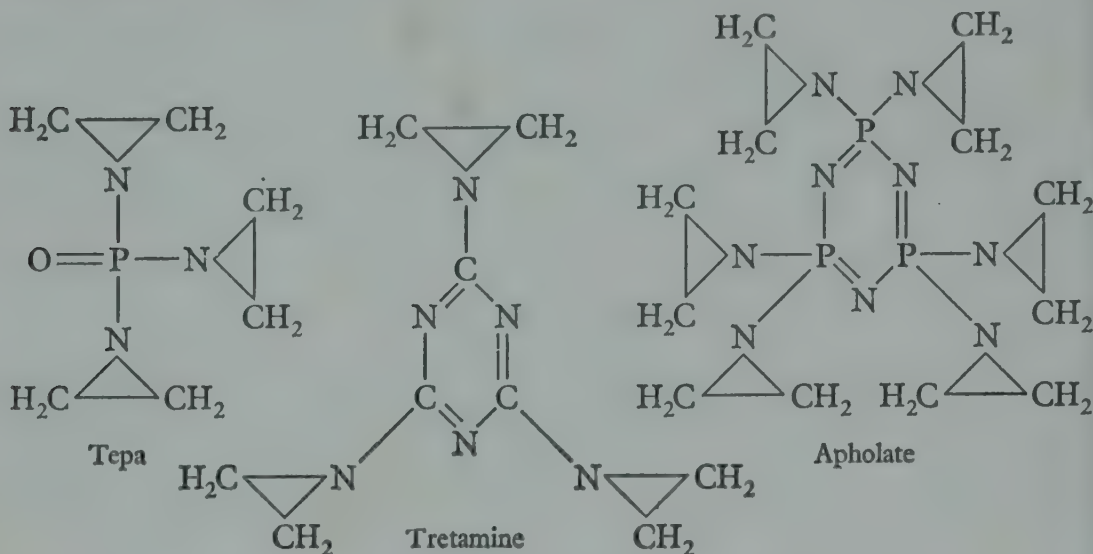
*Alkylating agents*

These compounds attack the nucleic acid after it has been synthesized. Large doses damage the nuclei so severely that the sperms or eggs may die. Smaller doses merely disrupt the chromatic material, causing lethal mutations. The treated insects produce eggs and motile sperm, but the progeny fail to mature. This parallels the effect of moderate doses of radiation and it is described as the radio-mimetic effect.

Some of the earlier alkylating agents were the nitrogen mustards which, in water, tend to form cyclic imonium compounds (I). This aroused interest in compounds with the cyclic aziridine ring (II), which is the basis of many successfully used chemosterilants. The instability and reactivity of this ring was considered to be essential for chemosterilant activity, but quite recently some compounds bearing methyl amine groups (III) have shown similar (though lower) activity.<sup>(17)</sup>



The most effective chemosterilants now used contain several aziridine rings, e.g. tepa, tretamine or apholate.



These compounds combine moderate solubility in water, alcohol and some organic liquids.

#### (f) Repellents<sup>(21, 35)</sup>

Since ancient times, men have tried to keep noxious insects away from their persons or their dwellings. Primitive methods include the smoke from smouldering fires, odorous substances applied to garments or hung up in the dwelling, and various plant or mineral preparations rubbed over the body. In the early decades of this century, essential oils were commonly used and recommended. From the 1930s onward, however, many thousands of synthetic chemicals were tested as repellents and some of them have now virtually displaced the natural products. The advantages of these synthetic repellents are as follows. They are almost odourless and therefore acceptable in use; they are more persistent; they are more consistent than natural substances, which are mixtures of components varying in effectiveness; lastly, they are relatively cheap.

The use of repellents is to be regarded as a palliative at best, not to be compared with satisfactory control measures, if these are possible. Furthermore, despite the good points of modern repellents, even the best fall short of what is wanted and probably the ideal repellent does not exist. Ideally, the application of a few drops of repellent should keep off noxious insects for an indefinite period. In practice, most modern repellents act by contact, with little action at a distance, so that they only protect the area actually treated. Furthermore, the period of protection is limited to a few hours (for treated skin) and a week or two (for treated clothing). Since, however, the repellents now in use devolved from very extensive trials, it seems unlikely that very much better examples of the type will be found. It is conceivable that something quite different might be achieved by systemic repellents (i.e. substances taken by mouth); but this line of approach has yielded little success so far.

*(i) Typical uses<sup>(61)</sup>**Against flying pests*

Flying bloodsucking insects, such as mosquitoes, stable flies, horseflies, biting midges, etc., usually land directly on exposed skin. Therefore repellents for protection against them are normally applied directly to the skin. Many repellents can be applied undiluted, but sometimes they are made up into creams or lotions, which may be considered cosmetically more desirable.

People frequently require protection from the bites of mosquitoes and similar insects when going on holiday, especially abroad. Unfortunately, they usually expose a large area of skin, which is difficult to protect. Some of the repellent gets absorbed into the skin and more of it is rubbed off by clothing, or removed by perspiration, during exercise. For these reasons, complete protection cannot be expected for more than a few hours, even with the best repellents.

Annoyance from horseflies, midges and certain other biting Diptera in Britain is usually experienced by agricultural and forestry workers and by fishermen. The main target is the hands and face. Protection of the latter can be secured by the use of impregnated veils. The use of wide-mesh netting (1 cm sq) impregnated with repellent and draped over the hat brim to enclose the face secures protection from biting insects without greatly reduced vision or ventilation.

*Against crawling pests*

In contrast to flying insects, the crawling bloodsucking arthropods frequently crawl over or among clothing before they reach the skin; so that repellents to deter them can be applied to the clothing. Two quite different types of pest are concerned. In the less hygienic quarters of towns and cities, doctors, health inspectors and social workers may find that they pick up fleas or even bed bugs in the course of their visits. Happily, this contingency is becoming rarer in present-day Britain. The other pests affect people sitting or lying on the ground in rural areas; sometimes this invites the attention of harvest mites or, occasionally, ticks. The sufferers may be agricultural workers, picnickers or soldiers on manoeuvre.

Repellents applied to outer clothing are smeared over the garments, mainly in the region of the openings, such as the neck-hole, cuffs, trouser legs, etc. Applications to clothing are generally more persistent than skin treatments; they may remain effective for a week or two.

*(ii) Typical substances*

A 'repellent', as understood by the public, is an empirical concept.<sup>(21)</sup> So long as the pest insects are prevented from annoying them, people do not bother to consider whether this is due to avoidance at a distance, to a strongly irritant action on contact, or to a rapidly paralysing effect. However, these various forms of protection will require rather different types of 'repellent'.

*Volatile repellents causing avoidance*

Volatile repellents are exemplified by essential oils, one of the best being citronella, extracted from the grass *Andropogon nardus*. It contains geraniol as its chief

ingredient, together with citronellol, borneol and various terpenes. Though its smell is not unpleasant, it becomes wearying after a time. Furthermore, it does not give the prolonged protection of the better synthetic repellents and accordingly is not widely used now.

### *Synthetic repellents acting on contact*

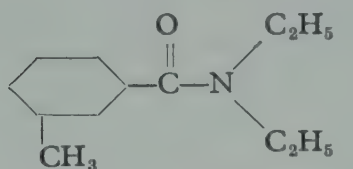
The two synthetic contact repellents most widely used against mosquitoes and biting flies are 'DMP' and 'deet', the latter being generally more effective.

Dimethyl phthalate ('DMP'), a colourless liquid. B.P.  $285^{\circ}\text{C}$ ;  $d$  1.19,  $n$  (20/D) 1.517. V.P. 0.01 mm Hg at  $20^{\circ}\text{C}$ .

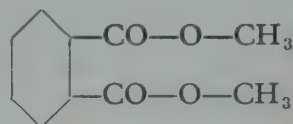
*N,N*-diethyl-*m*-toluamide ('deet'), a colourless liquid. B.P.  $139^{\circ}\text{C}$  at 2 mm Hg;  $d$  1.00,  $n$  (25/D) 1.521.

(N.B. The *ortho* and *para* isomers may be present in some samples, but it is the *meta* isomer which is most effective.)

DMP and deet were discovered in the U.S.A., about 1945 and 1955, respectively.



*N,N*-diethyl-*m*-toluamide



DMP

Other compounds which have been fairly widely used as repellents are indalone, 2-ethyl-1,3-hexanediol ('Rutgers 612'), dimethyl carbate and propyl *N,N*-diethylsuccinamate. These substances have been used in various mixtures with DMP (e.g. by American forces during and after the Second World War). They give somewhat better protection from a wider range of pests than individual repellents; but it is doubtful if this is justified in view of the limitations of all repellents mentioned earlier.

In 1948, the Swiss Geigy Company marketed a repellent 'Kik' consisting of a mixture of *N,N*-diethylbenzamide and *o*-chloro-*N,N*-diethylbenzamide. These compounds are rather similar to *N,N*-diethyl toluamide.

### *'Repellents' actually paralysing or killing*

Rapidly acting insecticides, such as pyrethrum or thiocyanates, have a protecting action equivalent to a repellent. Pyrethrum, however, is not very persistent and the thiocyanates are not suitable for application to human skin. For protection against harvest mites and ticks, a rapidly acting acaricide such as benzyl benzoate is often mixed with a repellent such as dimethyl (or dibutyl) phthalate.

'Moth balls', made of naphthalene or para-dichlor benzene, are sometimes spoken of as 'repellents', though they have no such action. They give protection only by the insecticidal effect of the vapour, when it is concentrated, and this is not a particularly rapid effect. The usage of repellent in this sense should be avoided.

### (g) Attractants

The remarkable achievements of modern insecticides have been somewhat offset by two drawbacks: the emergence of resistant strains and the toxic hazards to man and animals. All possible alternative measures should, therefore, receive attention, including the use of attractants, even though this is a highly specialized subject and does not, at present, look promising for pests of public health importance.

Properly speaking, an attractant should act at a distance, by causing insects to make orientated movements to its source. Substances which cause insects to aggregate after coming in contact with them are sometimes described as attractants, but more properly should be called *arrestants*.

The responses of particular insects to certain natural attractants may be astonishing. The odours emitted by some female moths are known to attract males from a distance as much as 2 miles. Food odours, though not as specific nor as potent as some sex lures, can be impressive; for examples, the aggregation of fruit flies and blowflies by odours of decaying fruit and carrion, respectively.

#### (i) Typical uses

For control purposes, attractants may be used in traps to assemble the pest insects. Alternatively, they may be combined with insecticides or chemosterilants to bring the insects to the controlling agent. Sex lures attract only one sex (usually the males); food lures often attract both. In addition, oviposition lures can be employed to induce large numbers of females to lay eggs on sites where they can be collected and destroyed.

Unfortunately, the use of attractants seems unpromising for several pests of public health importance. Thus, most parasites are ill provided with sense organs and are unlikely to be capable of responding. The bed bug, flea, lice and scabies mite fall in this category. Houseflies might appear more promising; but it appears that they are much less well provided with olfactory organs than other flies. They are largely attracted by visual stimuli; for example, aggregates of other flies. Nevertheless, some odours appear to be genuine fly attractants and they readily respond to sugar as an arrestant.

The possibility of using attractants for flying bloodsucking insects, like mosquitoes, are being explored. It appears, however, that response to odours is only one of a complex of chemical and physical stimuli which guide these insects to a blood meal.

#### (ii) Typical substances

As regards the attraction of insects to artificial lures, it may be noted: (i) that some compounds attractive at low dilution are repellent when concentrated; (ii) that some insects display inexplicable attraction to abnormal odours (e.g. the seaweed fly, which is fascinated by trichlorethylene vapour).

#### *Sex lures*

Some natural sex lures have been extracted and identified and a few have been synthesized (e.g. those of the bee, the gypsy moth, the silkworm moth and the

cockroach). In other cases, artificial sex lures have been synthesized, which have the same effects and can be used in traps (e.g. 'siglure' and 'medlure' for the Mediterranean fruit fly).

#### *Food lures*

Several workers have found that products of fermentation (aldehydes, ketones, alcohols) and putrefaction (amines) are attractive for houseflies, blowflies and fruit flies. It has generally been found that natural mixtures of the component odours are better than any individual ones. Thus, although ethyl alcohol or isovaleraldehyde are both attractive for houseflies, the best attractant is molasses or malt in the early stages of fermentation.<sup>(10)</sup> A good substitute mixture is malt, ethyl alcohol, skatole and acetal.

#### *Oviposition lures*

Ammonium salt solutions entice female houseflies to lay eggs on bran moistened with it, and ammonium carbonate is known to attract females but not males. These facts are probably related to the emission of ammonia by the natural oviposition sites of female houseflies.

### III · APPLICATION OF INSECTICIDES

#### (a) **Poison baits**

##### (i) *Uses*

Formerly, poison baits were employed against various indoor insect pests, such as cockroaches and Pharoah's ant. Their use has substantially declined with the introduction of synthetic residual contact poisons. At their best, baits are somewhat of a palliative, seldom obtaining complete eradication. Also, they are troublesome, unsightly and potentially dangerous to children and domestic animals. On the other hand, their usefulness may somewhat revive if the new synthetic insecticides become ineffective due to the emergence of resistant strains.

Poison baits may still find employment against certain garden pests (ants, earwigs, woodlice) which enter houses, but which are difficult to attack with residual poisons. They may be used, too, against houseflies in barns and stables, where some of their drawbacks do not apply. It is also possible that where low level resistance has developed in flies, the substance concerned may be more effective as a stomach poison than by contact, since a larger dose could be swallowed than would be picked up by the feet from a residual film.

##### (ii) *Equipment*

For liquid poison baits (e.g. for houseflies) it is desirable to offer the liquid in an absorbent material, since insects cannot easily drink from open water surfaces, without getting trapped. A good bait dispenser can be prepared from chicken-watering devices.<sup>(40)</sup> These consist of a jar of water (1 or 2 quart size) inverted in a 6-inch circular metal trough. The trough is filled with a ring of plastic sponge, which keeps soaked with bait.<sup>(40)</sup>

Ant baits in houses require protection from domestic animals and children. This can be accomplished by putting them in small tins pierced with holes or slits to allow the ants access to the bait.

### (iii) *Formulation of insecticide*

#### *Moist baits*

A wide variety of edible materials may be used as the basis; mixtures of carbohydrates (e.g. cereals) and proteins (e.g. fish meal) are readily consumed.<sup>(38)</sup> Bran is one suitable base, mixed with about the same amount of water and with 10% molasses added to increase its attractiveness. Alternatively, fish oil or edible vegetable oils may be added, instead of the water and molasses.

Poison is mixed first with the dry ingredient, at an appropriate rate: 2 or 3% of inorganic poisons, such as sodium fluoride, or 0.1% of synthetic poisons such as Kepone.

#### *Dry baits*

A simple dry bait for houseflies can be prepared by applying insecticides (e.g. various organo-phosphorus compounds) in acetone solution to granular sugar, so as to leave about 1-2% toxicant when the acetone evaporates.

A solid dry bait may be prepared from 50% sugar, 46% sand, 2% insecticide and 2% gelatine (or better still bacteriological agar). The sugar, sand and poison are mixed and the gelatine or agar liquefied with boiling water and then stirred into the mixture. This is allowed to set on small squares of wire screen attached to pegs.

#### *Liquid baits*

These are made from water containing 10% sugar, molasses or syrup. For houseflies, 0.1 to 0.2% of an organo-phosphorus insecticide is added. A similar bait, containing 0.3% sodium arsenite or 2% sodium fluoride, has been used against Pharaoh's ant.

### (iv) *Operation*

*Moist bait* is crumbled and scattered in small patches near houses where invading garden pests are likely to frequent. It is advisable to cover the bait with boards or tiles, to prevent it being taken by birds or domestic animals; this will also attract light-avoiding arthropods.

*Dry sugar bait* can be scattered on dry floors of barns and stables to kill flies. In muddy or moist places (e.g. chicken houses, stables or cowsheds) the solid bait on pegs may be used.

*Liquid bait* may be sprinkled on clean dry concrete floors against houseflies. For Pharaoh's ant, the bait is mixed with cake or minced meat to form a paste and portions placed in bait tins at suitable points.

### (b) **Insecticidal powders**

Insecticidal dusts, like other powders (e.g. face powder!), adhere spontaneously to solid surfaces. This adhesion may be assisted by electrical charges (either + or -)

given to the particles by frictional forces during passage through a dusting machine; but more important are the van der Waal forces at the actual points of contact. As particle size is reduced, the areas of contact decrease much less rapidly than the mass, so that smaller particles adhere more strongly. Calculations show that it takes an acceleration of about 4000 times gravity to shake off a 100-micron particle and as much as 500,000 times gravity to dislodge a 10-micron one.

Not only are finer powders more efficient at contaminating insects, but there is evidence that finely divided contact poisons are more potent, probably because of more rapid absorption through the cuticle. On the other hand, the particles of very fine powders tend to stick together, forming aggregations which then become the equivalents of large particles. Probably an optimum size is just below 10 microns. Commonly, however, insecticide diluents are merely specified by the sieves through which they will pass. Thus, the World Health Organization specifications for dusting powders containing DDT, *gamma* BHC, diazinon or malathion (WHO/SIF/16.R1; 17.R1; 21; 22) require 98% to pass 100 mesh (150 microns).<sup>(70)</sup> Some common dust diluents in U.S.A. are stated to pass 350 mesh sieves (44 microns).

#### (i) Uses

At one time, stomach poisons in powder form were used to some extent against pests of public health importance. For examples, Paris green was dusted over mosquito breeding places and sodium fluoride or borax powders were used against cockroaches. Safer and more efficient contact insecticides, however, have rendered these uses obsolete.

Contact poisons in powder form are used for certain domestic and medical insect pests. Probably the most important use is against ectoparasites. Thus dusts containing DDT, pyrethrum or malathion have been used for reducing widespread lousiness among prisoners or refugees in wartime or after disasters. (Other preparations are more suitable for reduction of head lice in normal circumstances.) Dust preparations are convenient for use against ectoparasites of domestic animals.

Contact insecticides in powder form are convenient for various domestic uses; against cockroaches and silverfish or for destroying wasp nests. On a larger scale, dust insecticides have been employed to destroy insects such as crickets or flies in refuse tips.

#### (ii) Equipment (Fig. 11)

The earliest dust applicators for insecticides were merely perforated containers, to be used like sugar casters. Simple modern types are various plastic containers which emit puffs of dust when squeezed briskly.

Slightly more elaborate is the hand-operated dusting gun, of which various models are available and which is covered by a World Health Organization specification (WHO/EQP/4.R1).<sup>(70)</sup> Air, driven by a hand-operated piston, is delivered to the base of a powder chamber and drives some of the dust out (usually through a coarse filter) through the discharge vent. This is usually fitted with an extension tube to direct the dust jet. The WHO specification states that 'the volume of discharge at each stroke of the plunger shall be the same at all angles at which the

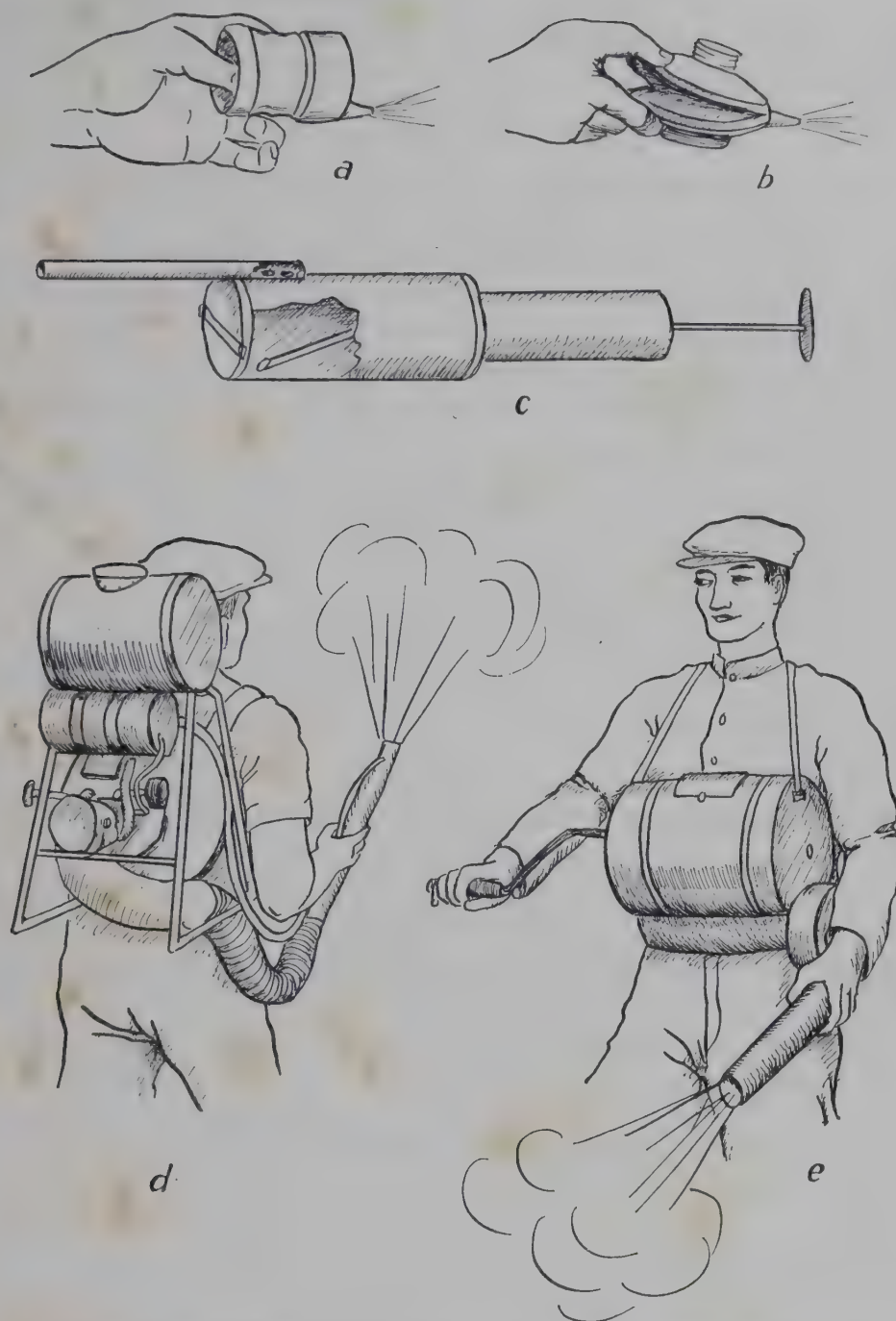


FIG. 11. *Equipment for applying insecticides in powder form.* (a) (b) simple hand-operated bellows types; (c) hand-operated piston duster; (d) power-operated knapsack duster (with certain modifications, the same basic equipment can be used as a sprayer); (e) hand-operated rotary blowing knapsack duster.

duster may be used'. Generally, however, there is inevitably some difference in the quantity of dust discharged at different angles.

For applying dusts outdoors on a larger scale (e.g. treatment of refuse dumps, mosquito breeding places, etc.) a rotary duster is desirable. These are widely manufactured for agricultural purposes. Air is generated by a centrifugal fan and this drives the dust out of a wide nozzle. The fan is either operated by a hand-driven

crank (in portable models; see Fig. 11e) or by gearing to the wheels, in wheeled types. Power-driven knapsack dusters are also used (Fig. 11d).

### (iii) Formulation of insecticide

Some early insecticide powders were of vegetable origin and the powdered raw materials contained suitable concentrations of active ingredient (e.g. pyrethrum flower-heads; derris root). When synthetic insecticides were introduced, however, it became necessary to dilute them with inert ingredients. Either solid or liquid contact poisons can be diluted with suitable mineral powders. The solid insecticides (e.g. DDT, *gamma* BHC) are usually mixed with some of the diluent before grinding, otherwise they tend to melt and fuse. Liquid insecticides are usually applied to the diluent in volatile solvents.

Various substances can be employed as diluents, the main criteria being:<sup>(25)</sup>

*Harmless to man* (e.g. absence of silicosis risk).

*Chemical compatibility with the toxicant.*

*Satisfactory particle size range* (see above).

*Ease of flowing and dusting* (i.e. absence of tendency to clog and ball up).

*Adsorptivity.* (This will depend on porosity. Very porous particles may absorb liquid insecticides and prevent their effective contamination of the insect.)

*Price and availability.*

Some of the commonest materials used for diluting contact insecticides are calcium silicates: e.g. kaolin, pyrophyllite, talc.

### (iv) Operation





For domestic uses against concealed insects, dusting guns are used to blow insecticidal powder into crevices where the pests may be hiding.

For use against persons infested with body lice, the delivery tube of the dust gun is directed under the clothing (see p. 251).

### *Air-borne droplets for dispersing insecticides*

#### *Nature and behaviour of sprays and aerosols*

Insecticides may be applied in the form of air-borne droplets. The sizes of droplets in different usages covers most of the range of meteorological phenomena. This is indicated by the following table, though it should be said that none of the terms are exact or universally agreed.

	oil fog		sea fog		cloud, mist		rain		
									
Droplet size in microns:	0.1	0.5	1.0	5	10	50	100	500	1000
	Aerosols						Sprays		

Broadly speaking, two main types of droplet cloud are used in insecticide applications: aerosols and sprays. The critical differences in behaviour between air-borne droplets of different sizes depend on the ratio between their mass and air resistance.

Larger droplets, having relatively more momentum, tend to impact on objects in their path; otherwise they soon fall to the ground. Accordingly, the main use of sprays is to wet surfaces evenly, generally in order to apply a residual film of insecticide.

Fine droplets tend to reach a constant velocity of fall in air; and since this terminal velocity is proportional to the square of the radius (Stokes' Law), tiny droplets fall very slowly indeed. Therefore, fine droplet clouds ('aerosols'), which tend to float in the air, may be used to contaminate flying insects with insecticide. Naturally, the finer the aerosol, the longer it remains air-borne. Particles considerably larger than  $20\ \mu$  tend to fall to the ground rather quickly. However, if the droplets become very small (say, below  $1\ \mu$ ), they have so little momentum that they will not readily impact on an insect, being carried past on the slipstream. An optimum size for use against mosquitoes is  $10\text{--}16\ \mu$ ; for houseflies  $20\text{--}25\ \mu$ .

It is important to realize that even moderately volatile liquids like water and kerosene do not form static aerosols, because the droplet sizes are continually shrinking, due to evaporation. Indeed, evaporation accelerates as the drops get smaller. For this reason, a proportion of non-volatile oil is often added to prevent the droplets from evaporating completely.

#### *Generation of sprays and aerosols*<sup>(28)</sup>

The atomization of liquids has been seriously studied, since it is important for oil combustion engines and chemical engineering as well as in relation to pesticides. Different methods are appropriate according to the droplet size required.

*Sprays* are generated by spray nozzles of many different designs, but nearly all designed to project an expanding sheet of liquid through the air. This becomes unstable and breaks up into threads, and then into droplets, under the influence of surface tension and the friction of the air.

*Aerosols* (ranging from smokes to mists) are produced in various ways. The energy for breaking up the liquid may be supplied mechanically (as by the centrifugal force of a spinning disc atomizer); or more commonly by the shearing force of a blast of air or hot gases (as in the twin-fluid atomizing nozzles). Another method depends on the volatilization of a liquefied gas (as in the 'aerosol bomb'). Finally, heat may be employed (as in smoke generators or electrical insecticide vaporizers).

### (c) **Sprays and sprayers**

#### (i) *Uses*

Sprayers have been used for years to apply mosquito larvicides (q.v.); but at present their most important use in medical entomology is the application of residual insecticidal films, mainly to the walls of human dwellings.

#### (ii) *Equipment* (Fig. 12)

##### *Nozzles*

The two most common types of spray nozzle give a fan-shaped spray and a hollow-cone spray respectively. The former consists of a slot at the end of a rectangular

tube, the pressure from above and below the slot causing the liquid to spread out sideways on emergence. In the hollow-cone nozzle, the liquid is usually made to swirl round a central plug against a divergent surface. Either type is suitable for

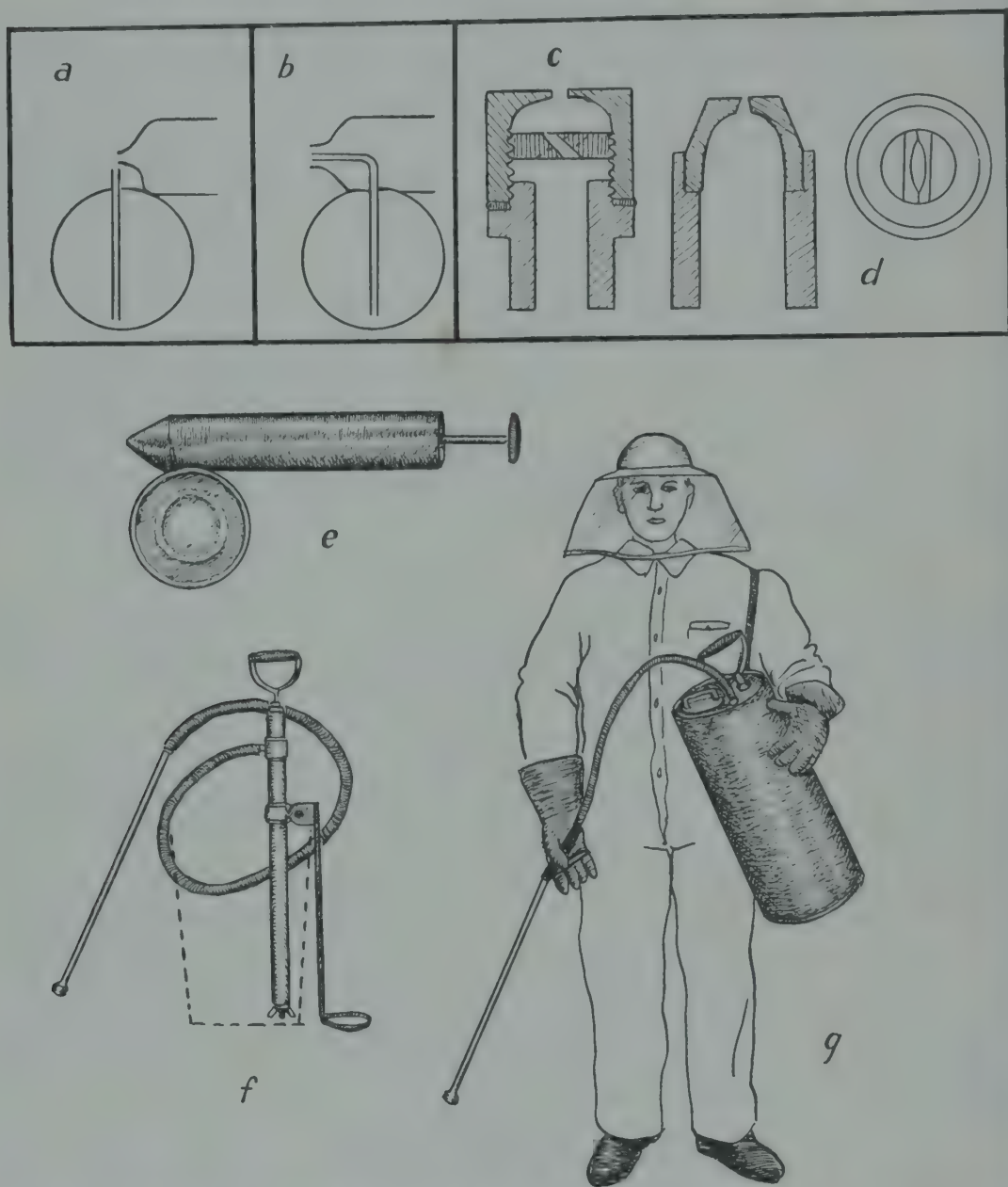


FIG. 12. *Equipment for applying insecticides in liquid form.* (a) (b) two types of simple atomizing nozzle; (c) swirling spray nozzle, producing hollow-cone spray (section); (d) jet spray nozzle, producing fan-shaped spray (section and plan); (e) piston-operated hand atomizer; (f) stirrup-pump type hydraulic sprayer; (g) compression type (pneumatic) knapsack sprayer as used by man wearing protective clothing.

applying insecticide sprays, but probably the flat fan-spray is most common for residual spraying. The droplets produced should be in the range 100–300  $\mu$ . Nozzles were formerly made of brass, but their orifices tended to erode, especially if suspensions of wettable powders were being sprayed. Now ceramic or stainless

steel nozzles are usually employed. Even so, the possibility of erosion should be remembered and nozzle apertures should be checked from time to time by measuring the output of spray. Worn nozzles should be discarded.

### *Sprayer design*

The manual power necessary to force liquid through the spray nozzle can be applied in different ways (via compressed air or by direct hydraulic pressure).

In the *compression sprayer* (or *pneumatic sprayer*) (Fig. 12g), air is pumped into the container above the liquid, until a pressure of 30 to 50 lb/sq in. is reached. The compressed air is then used to drive out the liquid along a hose, lance and spray nozzle. This principle can be used for small hand sprayers (1–2 quarts) or larger sprayers (2–4 gallons) carried on the back in use. The operator controls the delivery of spray by a tap. After a time the pressure falls and air must be pumped in again; this may need to be done several times before the reservoir is empty. Some types of sprayer include a constant-pressure valve which ensures that the spray is ejected under constant pressure while the air pressure lasts.

The World Health Organization gives a full detailed specification (WHO/EQP/1.R1) of a compression sprayer with a fan-spray nozzle and describes tests of the various criteria.

*Stirrup-pump sprayers* (Fig. 12f) require a two-man team for spraying. The spray liquid is mixed in a bucket into which the barrel of the stirrup pump is immersed and one man actuates this pump. The liquid is driven down a long hose to the spray lance held by the other operator. Apart from the disadvantage that this arrangement demands two men, it involves a risk of spilling the spray fluid from the open bucket and the spray pressure is uneven. The World Health Organization also gives a specification for this type of equipment (WHO/EQP/3.R1), but it is becoming rather less common than the compression sprayer.

*Hydraulic knapsack sprayers* are carried on the back and the liquid is pumped out along a hose and spray lance held in one hand by actuating a lever on the tank with the other hand. The spray pressure is rather irregular and the equipment is only suitable for applying oil larvicide at heavy doses.

### (iii) *Formulation of insecticide*

As already mentioned, sprays are employed to apply insecticide residues to the surfaces of walls, vegetation, etc., and also to apply larvicides to water surfaces. Insecticide is commonly incorporated in the carrier liquid, either in solution, emulsion or suspension.

The use of water as a carrier liquid has obvious advantages. It is cheap, safe and, being always locally available, does not have to be carried about with the equipment. Unfortunately, few contact insecticides are water-soluble so that water cannot be used as a solvent carrier, though it can be used for preparing emulsions or suspensions.

### *Solutions*

Kerosene (paraffin oil) has been widely used as a solvent carrier of insecticides. It has one advantage over aqueous preparations when sprayed on room walls; namely

that it does not leave marks, whereas aqueous sprays may leave smears. Provided that a grade with a sufficiently high boiling range (say 200–250°C) is used, the flash point is generally high (about 70°C) and the fire risk much less than would be imagined. Kerosene is sufficiently volatile for a heavy wall spraying to evaporate in a day or so.

Crude or burning kerosene is rather smelly; but the strong-smelling aromatic and unsaturated impurities can be removed by treatment with sulphuric acid, giving refined kerosene. The only disadvantage of this as an insecticide carrier is that it has rather lower solvent capacity for insecticides than the crude product. Thus:

	Per cent solubility in	
	Refined kerosene	Burning kerosene
DDT	(approx.) 3	(approx.) 8
gamma BHC	( „ ) 2	( „ ) 3

To obtain the rather high concentration of chlorinated insecticides needed for residual deposits may require some trouble. One method is to add the insecticide to the kerosene several days before it is required, keep it in a warm place and stir at intervals. Another method is to melt the insecticide gently over a small flame and then pour it slowly into the kerosene with vigorous stirring. Alternatively, it may be advisable to employ auxiliary solvents, which will also help to prevent crystallization in cold weather. Suitable auxiliaries are xylene and cyclohexanone. Addition of 10% of either of these auxiliaries will increase the solubility of DDT in refined kerosene to 10%.<sup>(4)</sup>

Perhaps the simplest method of preparing kerosene solutions is to use concentrates (containing auxiliary solvents) prepared by reputable manufacturers. The process is then simplified to mere quantitative mixing.

### Emulsions

Aqueous emulsions permit the use of the cheap and widely available water to be used as a major part of the carrier liquid. Their use in applying residues to walls of dwellings has declined slightly in recent years in favour of suspensions (q.v.). They are still useful for larvicides against mosquitoes in special circumstances; e.g. in polluted water or against forms like *Taeniorrhynchus* which do not live at the surface of the water. To prepare an insecticide emulsion, the insecticide is dissolved in some suitable solvent (e.g. xylene, toluene, aromatic petroleum fractions such as polymethyl naphthalenes) and this is dispersed in water with the aid of an emulsifying agent. Emulsifying agents have molecules partly hydrophilic and partly hydrophobic which tend to orientate themselves in the interface between water and an oily or fat-solvent liquid. In an emulsion, a mono-molecular film of emulsifier round the dispersed droplets repels other droplets and prevents aggregation. The oldest and most readily available emulsifiers are natural colloids with molecules carrying polar and non-polar groups. These include many proteins and hydrocarbons such as casein, starch and various gums and resins. Many synthetic emulsifiers are now available, built on the general plan of a polar group with a long

hydrocarbon chain; the polar group being attracted to the water and the hydrocarbon chain to the oil or solvent. In some of these compounds, the polar group is non-ionic; but in others it may be a cation (alkali salt) or an anion (halide). The type of emulsifier, however, is designated according to the other ion, i.e. the one bearing the hydrocarbon chain. Thus, sodium naphthyl sulphonate is an anionic emulsifier, whereas cetyl pyridinium bromide is a cationic agent.

*Emulsion concentrates* are convenient for preparing insecticidal emulsions in the field. These are of two kinds: the 'mayonnaise' type and the 'soluble oil' type. The former is actually a concentrated emulsion containing very little water. It needs merely further dilution, but this involves considerable stirring. The 'soluble oil' type contains no water; it is the solvent (dispersible) phase, containing the insecticide and a suitable quantity of emulsifier. On adding it to water, a good emulsion forms spontaneously, with very little stirring. This type of preparation is probably more widely used than the mayonnaise type today, on account of its greater convenience. Strictly speaking, it should be called an 'emulsifiable concentrate' rather than an 'emulsion concentrate'; but the latter term is widely used. The World Health Organization gives specifications for (soluble oil type) emulsion concentrates of DDT, *gamma* BHC, etc. (WHO/SIF/4.R2, WHO/SIF/5.R2, etc.).<sup>(70)</sup>

The stability of a diluted emulsion depends on its liability to 'break' or to 'cream' and it is important to distinguish these two phenomena.

'Breaking' of emulsions is the separation of the two phases by coalescence of the droplets. After separation, the two phases cannot be re-emulsified by mere shaking. Badly made or unstable emulsions may break too soon, but it is sometimes an advantage for an emulsion to break fairly soon after application (e.g. on foliage, to contaminate it with oil, which might otherwise run off). The required stability can be attained by the use of a suitable emulsifier.

'Creaming' of emulsions is merely due to the oil droplets moving to the top of the liquid (e.g. cream on milk) and forming a layer there without coalescing. Creamed emulsions can be redistributed by shaking. Creaming can be prevented by forming emulsions with very small droplets which are prevented from rising by frictional forces.

### *Suspensions*

Aqueous suspensions of insecticides are now used extensively in pest control, to a large extent displacing solutions or emulsions, for applying residual deposits. This is partly because suspensions are cheap and easy to prepare; but also the residual deposits from them on porous materials are generally more efficient. When a suspension is sprayed on to a porous wall surface, only the water sinks in, leaving all the insecticide on the surface, where it is available to contaminate insects. In contrast, when the liquid phases of solutions or emulsions sink into wall pores, they carry in some insecticide, which is therefore lost. On non-porous surfaces, however, emulsion residues may be more efficient.

Suspensions are prepared from water-dispersible powders available commercially. These 'wettable powders' comprise the insecticide, an inert carrier or diluent and a wetting agent. The proportions of insecticide vary, but preferably range

between 25 and 75%. The higher the percentage, the less will the final insecticide deposit be masked (or covered up) by inert ingredients. The inert diluent is necessary with solid insecticides to assist in fine grinding and also to counteract the high density of most chlorinated hydrocarbon insecticides. In a good preparation, the insecticide particles and diluent should be firmly associated; otherwise they may get separated by vibration during transport of the preparation in bulk. With liquid insecticides, the diluent also acts as a carrier. Suitable materials for diluents are natural or synthetic silicon oxides or calcium silicates. The surface-active materials (wetting agents) play the same part as emulsifying agents; that is, to prevent aggregation of the suspended particles. One of the most important qualities of a wettable powder is the stability of the suspension prepared from it. A good product must remain in suspension during the period of spraying, otherwise the concentration of insecticide applied will progressively fall as the suspension deposits. The World Health Organization gives specifications for water-dispersible powders of DDT, BHC, methoxychlor, chlordane, dieldrin, diazinon and malathion (WHO/SIF/1.R2; 2.R2; 7.R1; 8.R1; 3.R2; 9.R1; 10.R1).<sup>(70)</sup> Among other criteria a suspensibility test is described. Wettable powders must give satisfactory performance not only when fresh but after storage in bulk, possibly under tropical conditions. Therefore provision is made for accelerated storage tests, employing pressure and heat.

*(iv) Operation for residual spraying*

Probably the most important use of spraying in public health entomology is for application of residual films of insecticide in dwellings. To control house-haunting pests (flies, mosquitoes, bed bugs, etc.) the following deposits have been recommended (mgm/sq ft): DDT, 200; *gamma* BHC, 40; dieldrin 50; malathion, 100. To apply these deposits, it is necessary to know the application rate of a sprayer as normally used. Given a standard machine operated at a particular pressure, the spray rate depends on the skill and experience of the operator. Usually the aim is to wet a surface thoroughly to a point just short of run off; this is normally between  $\frac{1}{2}$  and 1 gallon per 1000 sq ft. Spray operators should be trained to apply standard amounts and the insecticides can then be made up accordingly. Thus, for a spray applied at 1 gal/1000 sq ft, the following formulae will give the required deposits:

DDT, 75% wettable powder:  $9\frac{1}{2}$  oz per gal water.

„ 20% solution or emulsion concentrate: 1 pt to  $3\frac{1}{2}$  pts kerosene or water.  
*gamma* BHC, 50% wettable powder: 3 oz per gal water.

„ „ 20% solution or emulsion concentrate: 1 pt to 22 pts kerosene or water.

Other formulations may be calculated by simple proportions.

The efficiency of the operator in spraying correct dosages can be checked by pinning up filter papers at random on the surfaces to be sprayed and subsequently removing them for analysis by a chemist equipped for this work. The results will show the actual deposit and how it varies from place to place. (The only flaw in

these estimates is due to the fact that spray men tend to give special attention to the test papers, giving them an extra heavy dose!) Experiments of this type have shown that deposits of even the best operators vary greatly from place to place. Furthermore, owing to fall out of spray and droplets bouncing off the wall, only about 80% of the expected deposit arrives and a lot of insecticide is found on the floor below.

#### (d) Aerosol generators

##### (i) Hand atomizers (Fig. 12e)

###### *Uses*

For many years a simple type of hand-operated atomizer (generally known as a 'Flit' gun) has been used to spray insecticides indoors, mainly against houseflies. The same type of atomizer may be employed to apply concentrated high-spreading mosquito larvicides (see p. 135).

###### *Equipment*

The sprayer consists of a hand-operated piston, supplying the air, a liquid reservoir and a simple nozzle. In some types, the spraying is *intermittent*, corresponding to the strokes of the piston. In others, a more or less *continuous* action is possible, owing to a build-up of air pressure in the reservoir above the liquid.

There are two main types of nozzle: one in which the air and liquid jets are opposed at right angles and the other in which the liquid jet is introduced concentrically into the air jet (Fig. 12a, b). In both cases, the movement of air over the mouth of the liquid feed sucks up the insecticide.

The droplet size range produced is rather variable, but a large proportion should be below 50  $\mu$ . With badly designed or constructed atomizers, a proportion of large drops are produced, which fall out rapidly. A good atomizer should show no gravity deposition within a yard from the nozzle.

The World Health Organization provides specifications for these sprayers (WHO/EQP/2).<sup>(70)</sup>

###### *Formulation of insecticide*

For domestic use ('fly sprays'), the usual carrier is odourless kerosene and the principal insecticide is pyrethrum, to give a rapid 'knock-down'. A concentration of 0.1% pyrethrins is adequate, or its equivalent of synergized pyrethrins. To this may be added a small quantity of synthetic insecticide to improve kill. A typical formula is as follows:

0.025%	pyrethrins
0.2%	piperonyl butoxide
0.5%	DDT or 0.1% gamma BHC

###### *Operation*

Theoretically the atomizer is intended to produce an aerosol; but to produce an aerosol effective throughout a large room would entail much hard work. There is

no doubt that the use of this type of atomizer is partly as a direct, aimed, spray and only partly for its aerosol effect.

### (ii) *Liquefied gas aerosol dispensers*

#### *Uses*

The prime importance of aerosol dispensers in the field of public health is their use for disinsection of aircraft. With the great and expanding volume of air traffic there are increasing opportunities for insect pests (including disease vectors, possibly infected) being carried from one continent to another. Many countries demand disinsection of aircraft coming from possible danger areas and the method recommended by the World Health Organization involves use of aerosol dispensers. This does not normally concern Britain, since the risks of disease vectors becoming established here are negligible. However, certain aircraft in transit (e.g. from Africa to Asia) must be treated at London Airport <sup>(64, 71)</sup>.

In other respects, aerosol dispensers are used for the same purposes as hand atomizers (e.g. domestic purposes), being a labour-saving improvement. They are not, however, suitable for applying larvicides.

#### *Equipment*

The design of an aerosol dispenser ('aerosol bomb') is simple. It consists of a metal can with a tube running up the centre to an orifice (0.01 to 0.02 in.) at the top, controlled by a simple press valve. The can is filled with 'Freon' (trichlorofluoromethane and dichlorofluoromethane) liquefied under about 25 lb/sq in. pressure, together with non-volatile oil, containing insecticide. When the valve is opened, the Freon acts as a propellant, rushing out and vaporizing, leaving the insecticide solution dispersed in the air as an aerosol.

The droplets produced should be in the range 1–50  $\mu$ , with not more than 20% having a diameter above 30  $\mu$ .

Dispensers can be of various sizes ranging from very small ones, intended to empty completely in one operation, up to large dispensers of about 5 lb, which can treat up to 1 million cubic feet.

#### *Formulation of insecticide*

Three standard formulae are as follows:

	<i>Per cent in weight</i>		
	<i>WHO standard</i>	<i>American G-1492</i>	<i>Pyrethrum Board Kenya</i>
Pyrethrins	0.4	1.4	1.7
Sulphoxide (synergist)	—	—	2.0
DDT	3.0	2.0	—
Isopropyl myristate	—	—	2.4
Xylene	7.5	8.0	—
Mineral oil	2.9	—	13.9
Propellant	85.0	84.0	80.0

#### *Operation*

In aircraft disinsection, the dispensers are operated by a person walking slowly down the aisle, directing the jet upwards, but at least  $\frac{1}{2}$  metre from the ceiling. In the

'chocks-away' procedure, treatment is made with the passengers aboard, between the time of door closure and take-off. Dosage is by time of operation, most dispensers emitting about 1 gm per second. For aircraft disinsection dispensers are operated for 10 seconds per 1000 cu ft; for domestic purposes 3-5 seconds per 1000 cu ft are recommended.

### (iii) *Insecticide fogging machines*

#### *Uses*

The production of large quantities of aerosol may be useful for the rapid treatment of towns (especially large buildings) in case of insect-borne epidemics. Alternatively, insect fogging has been used out of doors to obtain temporary relief from biting flies. In neither case is any residual control achieved and the method is expensive and normally only justified in special circumstances.

#### *Equipment*

*Air blast atomizers*, similar to paint spray guns, may be used, the air being supplied by a mechanical compressor.

A *hot-air blast atomizer* is the 'Todd Insecticide Fog Applicator' or TIFA. Air heated by a petrol burner is used to atomize the insecticide in an internal nozzle. The TIFA is a large machine (weight 600 lb), usually transported on a trailer. Its output ranges from 20 to 40 gal/hr giving an aerosol 10-50  $\mu$  droplets, the size range being controllable.

The *exhaust of pulse-jet engines* operate other fogging machines, some of them being portable, e.g. the 'Swingfog' (weight 24 lb; output 1.5 to 2.7 gal/hr; aerosol range 8-24  $\mu$ ), the 'Dyna-fog Junior' (weight 15 lb; output 1.7 to 8.6 gal/hr; aerosol range 8-78  $\mu$ ).

The *spinning disc mist generator* works on a totally different principle. Insecticide solution is introduced between discs rotating at high speed (about 15,000 rpm) and powerful centrifugal forces fling off the liquid in the form of small droplets. E.g. 'Microsol' generators; the smallest model is portable (weight 12 lb; output 0.4 gal/hr; aerosol range 5-60  $\mu$ ). Larger models are available but they produce rather coarse mists.

#### *Formulation of insecticide*

Mist blowers will disperse solutions or emulsions (e.g. 5% DDT emulsion or solution in fuel oil, or a stronger solution of 30% DDT in methylated aromatic solvents). In the hot-air or engine exhaust atomizers, an appreciable proportion of the insecticide may be decomposed.

#### *Operation*

Portable models can be used in buildings. The large machines are for outdoor use, being towed along slowly behind a vehicle. They can only be operated successfully in very calm conditions; that is, with little wind and early in the day before convection currents are prevalent.

(iv) *Insecticide smoke generators*

*Uses*

Smoke generators dispensing DDT or *gamma* BHC are employed to some extent in horticulture (e.g. in greenhouses), but they are not very suitable for use indoors. The main use of smokes against domestic insect pests is the burning of mixtures of pyrethrum with a slow combustion mixture to destroy mosquitoes in bedrooms in the evening. A common form is the 'mosquito coil', mainly produced in Japan. Ordinary combustion, however, destroys much of the pyrethrins present (80–95%). Improved dispersion with less combustion may be achieved by adding substances which generate gas on heating (e.g.  $\text{NaHCO}_3$  or  $(\text{NH}_4)_2\text{C}_2\text{O}_4$  which emit  $\text{CO}_2$ ). An improved pyrethrin smoke generator employs as 'reaction propellant' 3,7-dinitroso-1,3,5,7-tetra-azabicyclo-[3,3,1]-nonane, which gives off nitrogen on ignition.

*Equipment*

No equipment is needed.

*Formulation of insecticide*

(1) *A typical mosquito coil* may be made from a paste containing 20–40% pyrethrum powder; 34–40% combustible filler (e.g. wood flour); 25–30% water-soluble gum; a trace of fungistat and a dye.<sup>(46)</sup>

(2) *Pyrethrum reaction aerosol powder* comprises 50% pyrethrum powder; 6% piperonyl butoxide; 44% reaction propellant. Suitable quantities are sealed in small plastic bags.<sup>(9)</sup>

*Operation*

A mosquito coil may be simply ignited by a match. The reaction aerosol powder must be ignited by flameless heat, e.g. a nitrate fuse placed on the plastic bag (which may be held on a shovel).

(v) *Electrical insecticide vaporizers*<sup>(3, 24, 63)</sup>

*Uses*

Electrically operated thermal insecticide vaporizers are available commercially, being intended for domestic insect pests, especially houseflies. They have been quite widely installed in restaurants, kitchens and food stores.

*Equipment*

The apparatus consists of a metal cup containing insecticide, which is maintained in a liquid condition by an electric heater controlled by thermostat. One or more units are fixed to the wall, according to the size of the room.

*Formulation of insecticide*

Undiluted insecticide is used, commonly DDT, *gamma* BHC or a mixture of the two.

*Operation*

The vaporizing units are intended to operate continuously. The insecticide is either sublimed or emitted as a very fine aerosol. It is not clear whether the aerosol affects the insects directly or whether the action is mainly due to the deposits which build up, especially on the walls and ceiling near the vaporizers.

The quantity of insecticide given off varies according to the temperature and prevalence of local air currents, being in the region of 0.25 to 2.0 gm per unit in 24 hours. In addition, the insecticidal efficiency (and the possible toxic hazard) of the apparatus depends on ventilation. This varies considerably, since the air in a room may change completely from five to several hundred times a day, according to structure and conditions.

(e) **Insecticidal lacquers**<sup>(5, 8, 23)</sup>

(i) *History*

In the years immediately following the Second World War, the newly introduced synthetic insecticides were tried out in diverse formulations. One idea was to mix DDT with whitewash, distemper or paint to obtain insecticidal wall decorations. Unfortunately, it was found that much of the contact action was lost by the DDT being masked by whitewash particles or embedded in the paint film. Then it was discovered that, if a sufficiently high concentration of DDT was included in certain oil-bound paints, the insecticide would migrate to the surface and become extruded as a bloom of crystals. Furthermore, this bloom would be renewed, if wiped away. Subsequently, it was found that even better results could be obtained with insecticides incorporated in certain synthetic resins, which produced insecticidal lacquers.

(ii) *Uses*

Insecticidal lacquers are rather expensive but very satisfactory in other respects, being persistent and not unsightly. They have been most successfully used against kitchen pests, for example, German cockroaches and Pharaoh's ant in hospitals and similar institutions. In some early trials, a single application was able to control cockroaches in the galleys of merchant ships for over a year.

(iii) *Formulation of insecticide*

Various types of synthetic resin combinations have been used, including urea-formaldehyde, coumarone-styrene, coumarone-indene and chlorinated synthetic rubber. The first mentioned is probably most widely used.

Synthetic resin alone is not satisfactory and a plasticizer is added to encourage the blooming of insecticide. The rate of release of insecticide is governed by the resin to plasticizer ratio, being faster with the softer finish containing more plasticizer. A typical formula is as follows:

Urea-formaldehyde resin	50 parts
Castor oil alkyd resin (plasticizer)	50 „
Butanol and xylol (solvents)	50 „
Insecticide	10 „

Before use, an acid accelerator is added, to promote polymerization and hardening. A common one is 10% sulphuric acid in butanol, one part being added to 20 parts of lacquer.

Various insecticides have been incorporated in lacquers, including DDT, *gamma* BHC, aldrin, dieldrin, pyrethrins and malathion. The liquid ones are extruded as a greasy film, not as crystals; and some compounds give off insecticidal vapour through the resin (*gamma* BHC, aldrin, malathion).

The most persistent action, however, is obtained with dieldrin or DDT. A resin containing 5% dieldrin may remain highly active for over a year.

#### (iv) *Application*

Insecticidal lacquer may be conveniently applied by a large paintbrush. Care is needed, because the lacquer is somewhat corrosive (owing to the acid accelerator) and also, once it has set hard, it cannot be removed by solvents or paint strippers. Splashes on skin or clothing should be avoided; but when they do occur, they should be removed at once with solvent applied by the manufacturers. This solvent should also be used to clean brushes and other equipment after use.

It is not generally necessary to apply lacquer to whole wall surfaces. The aim should be to put barriers between the insects' hiding places and their food. For this purpose, bands about 4 inches wide are painted around skirtings, door and window frames, legs of tables, entry points of water pipes, electric conduits, etc.

The lacquer may be applied to any clean, non-porous surface (hard paint, glazed tiles, glass). Paintwork less than three months old should not be treated, however, and metals should be pre-treated with a primer to avoid corrosion. It is also inadvisable to treat surfaces constantly wet or frequently washed.

#### (f) **Insecticide impregnation**

Residues of persistent contact insecticides may be applied to various materials, by dipping the latter in solutions (or, in some cases, emulsions) of insecticide, so that a particular amount remains after drying.

##### (i) *Impregnation of fabrics*

Towards the end of the Second World War, the underwear of British troops on active service was impregnated with 1% by weight of DDT to destroy any lice they might acquire.<sup>(33)</sup> DDT impregnation of woollen garments against clothes moths was formerly undertaken by dry cleaners,<sup>(66)</sup> but this is now rare. More efficient is the impregnation of wool in the dyebath by hot emulsions of dieldrin, which is still widely used for carpets, etc.

##### (ii) *Impregnated suspended objects, against flies*<sup>(4, 56)</sup>

Ribbons, cords and cardboard objects have been impregnated with insecticides and hung up in places infested with houseflies to kill those which rest on them. Cords  $\frac{1}{5}$  to  $\frac{1}{10}$  inch in diameter, crepe bandage or narrow strips of wire mesh (18 × 14 per inch) have been used for this purpose. Formerly they were usually impregnated

with DDT or dieldrin; more recently, organo-phosphorus insecticides have been used, owing to the widespread resistance to chlorinated insecticides.

These cords, ribbons, etc., are usually hung from the ceiling, allowing about 1 metre for each sq metre of floor (30 ft cord per 100 sq ft). The most effective treatments are parathion or diazinon, which are available commercially. Because of the toxicity of the chemicals, it is recommended that cords be prepared by experienced persons only and the directions on commercially available cords and strips should be carefully followed. While this measure against flies has been used in canteens, it may be thought rather unsightly for human dwellings; it is, however, extensively used in dairy barns (e.g. in Denmark, where farming standards are high).

Impregnated cardboard shapes, hung up to attract and destroy flies, were popular in the early days of DDT, but are seldom seen now. One firm, however, markets cardboard circles impregnated with dimetilan. These are coloured red and printed with fly shapes, supposed to attract other flies to them.<sup>(69)</sup>

### (g) Larvicides<sup>(45)</sup>

Various pest insects with aquatic larvae may be attacked with larvicides (including blackflies and non-biting Chironomidae); but in Britain the only important forms are mosquito larvae. These may breed in a wide range of habitats, ranging from lakes or swamps to water butts or underground seepages.

#### (i) Mineral oil larvicides

##### *Characteristics of larvicidal oils*<sup>(53)</sup>

In 1892 the American, L. O. Howard, discovered that a film of kerosene applied to water will kill mosquito larvae breeding in it; and this method has been followed for many decades. Various unrefined mineral oils have been used as larvicides and at first the choice was quite empirical. Later research centred attention on three essential criteria: toxicity, spreading pressure and stability.

**Toxicity.** It is a common misconception that oil films kill mosquito larvae by suffocating them; but experiments have shown that this is seldom true. Asphyxiation of insects is generally slow (see p. 85) and, in any case, mosquito larvae can survive for many hours by utilizing air dissolved in water. It is true that oil larvicides penetrate the tracheal breathing tubes of the larvae, but their lethal action is generally due to toxic components of the oils. These are, apparently, the aromatic hydrocarbons (the paraffinic compounds being relatively non-toxic). A high aromatic content, however, is not necessary and may confer disadvantages (e.g. too high a specific gravity).

Most unrefined oils are, in fact, adequately toxic. It is, of course, essential for them to penetrate the tracheal system. The most efficient petroleum oils are in the medium (200–300°C) boiling range; more volatile oils tend to be irritating and cause the larvae to avoid them.

The larvicidal potency of an oil sample may be tested simply in the laboratory by exposing about 50 well-grown larvae to a film 10  $\mu$  thick (1 cc to 1000 sq cm). After 30 minutes the larvae should be removed without being further contaminated,

preferably by cleansing the surface by allowing the receptacle to overflow. The death rate should be recorded after an hour, at which time a good larvicide should have killed all larvae.

*Spreading pressure.* This property, expressed in dynes per centimetre, is a measure of the force exerted by a film on water to overcome resistance to its spread. It is zero for non-spreading oils like medicinal paraffin, which remains in globules even on a clean water surface. Kerosene has a value about 10 dynes/cm, but a good larvicidal oil should have a value about 23 dynes/cm; and if specially good spreading (and penetration among aquatic vegetation) is required, a spreading pressure of 46 dynes/cm is recommended.

The spreading pressure of mineral oils is generally due to impurities exercising surface action and it can be reinforced by the addition of 'spread-aiders' (such as sodium alkyl sulphate or an alkylated aryl polyether alcohol). Commercially available anti-mosquito oils (e.g. 'Malariol H.S.') are now generally fortified in this way.

A simple method of measuring the spreading pressure of oils (and also the resistance of natural barriers to spreading) has been described by N. K. Adam.<sup>(1)</sup>

*Stability.* The factors responsible for the stability of oil films after spreading are complex and not fully understood. It is known that the most stable oils are those consisting of wide and overlapping cuts with either very high or very low aromatic content and they should not contain fats or fatty acids as spread-aiders.

The quality can best be judged by an empirical field test, applying a standard quantity to a pool on a windless day and rejecting any specimen which does not form a stable film lasting at least two hours.

### *Equipment*

The hydraulic or pneumatic knapsack sprayers, described on page 123, are suitable for applying larvicidal oils. The oils should be sprayed over the entire surface where larvae may occur. The dosage should aim at producing a film not less than 10  $\mu$  thick. This corresponds to 9 gallons per acre or 0.2 gallons per 1000 sq ft; but in practice a dosage of 25 gallons per acre is usual, to allow for errors and irregular spreading.

In contrast to the light dosage of insecticide-fortified oils, described in the next section, this 'heavy oiling' has certain advantages. The oil tends to kill vegetation at the sides of ditches, keeping them open and proving that the larviciders have done their job. Also, though the oil has no lasting toxic action, there is some evidence that it repels ovipositing female mosquitoes for a day or so.

### (ii) *Insecticides in oil solution*

#### *Characteristics of insecticide solution larvicides*

The lethal dose of DDT for mosquito larvae is of the order of 10 mgm per m<sup>2</sup>; this would be applied in 1.43 pints of a 5% solution per acre, corresponding to a film 0.2  $\mu$  thick. Such a small quantity is difficult to apply and the normally recommended dosage is 2 to 4 pints per acre.

These thin films, though killing larvae reliably, do not have any residual action.

*Equipment for applying insecticide-solution larvicide*

The dosage is too light for application by knapsack sprayers but hand atomizing guns (p. 127) may be found suitable. Alternatively, providing sufficient spread-aider has been incorporated to give high spreading pressure (about 46 dynes/cm), the larvicide may be applied in small doses (up to 2 oz) allowing the oil to spread itself over the surface. A maximum individual dose of 2 oz should be sufficient to destroy larvae over an area of 2000 sq ft (the area of a circle of radius 25 ft); this corresponds to 2 pints/acre. Alternatively, various larvicide applicator guns are available. For example, the 'Eagle' or 'Waco' Force Oiler is a small squirt gun, holding a few ounces of oil larvicide. It is carried in one hand and, by pressure of the trigger, ejects a jet of about 1 cc to a distance of 15–20 ft. This is sufficient to treat an area of 2 sq yards of water surface.

*(iii) Aqueous larvicides*

Emulsions and suspensions of insecticides in water have been used; but since their effect is dissipated through the depth of the water, they tend to be less efficient than oil solutions, which are concentrated at the surface, where nearly all mosquito larvae spend most of their time. An exception is the *Mansonia* group, which draw their oxygen from plants, and cannot be controlled by surface treatments.

Aqueous solutions of organo-phosphorus insecticides (e.g. 0.5 ppm trichlorphon; 0.25 ppm mevinphos; 0.01 ppm parathion) have been used to control mosquitoes in irrigation water, in California.<sup>(29)</sup> Though apparently rather dangerous, these compounds become inactivated in a few days and may, in fact, be less harmful to wild life than the persistent chlorinated hydrocarbon insecticides.

*(iv) Larvicides in powder form*

Paris green was commonly applied as a dust, suitably diluted with any available material, including road dust. When DDT and other new insecticides were introduced, they were also tried as larvicides in powder form. The chief advantage of this type of treatment seems to be that, in application by a rotary dust-blower (p. 119) from the windward side of a large breeding site, advantage can be taken of the wind to carry the insecticide over the area to be treated.

*(v) Larvicidal granules<sup>(27, 57, 68)</sup>*

Mosquito larvae breeding in ponds thickly set with reeds or other aquatic vegetation present difficulties of penetration by liquid larvicides. A convenient effective treatment for such sites is to scatter insecticidal pellets (0.6–2 mm) or granules (0.25–0.6 mm). These may be scattered by hand, dusting machines or from aircraft.

Two types may be used. One form is compounded with a relatively heavy mineral base (e.g. attapulgit, a calcium silicate). This falls to the bottom of the water and slowly disintegrates. Provided that the water is shallow, the insecticide disperses and kills the larvae. Another is bound, with a sticky oil emulsion, to pellets of vermiculite (an exploded, hydrated variety of biotite, one of the components of mica). These pellets are light and float on the water, gradually dispersing insecticide. The method has been successfully used with dieldrin, malathion and even Paris green.

(vi) *Larvicidal brickettes*<sup>(27, 58)</sup>

Larvicidal brickettes are convenient for long-lasting treatment of static water breeding sites. Small ones (5–10 gm) can be used in rot holes in trees or water butts, etc.; larger ones (e.g. 300 gm) may be used in septic tanks, which often breed culicine pest mosquitoes. These brickettes are compounded of wettable powders containing about 50% active ingredient, together with cement or plaster. Two typical formulae are:

{	3 parts sawdust	{	10 parts sand
	20 „ plaster of paris		2 „ cement
	7 „ wettable powder (DDT or BHC)		1 „ wettable powder (dieldrin)

For septic tanks, the brickette must be kept at the surface, otherwise it will be buried in sludge. This can be done by fixing it with wires or by attaching it to a wooden float.

(h) **Fumigation**<sup>(55)</sup>(i) *House fumigation*

The technique of fumigation depends, to a large extent, on the means of containing the gas or vapour. In the simplest logical situation, pests are fumigated in the infested structure, e.g. a building or ship.

In public health entomology, houses have been fumigated to destroy bed bugs, fleas, cockroaches, clothes moths, etc. Most infested houses are poor at retaining gas and only the most toxic fumigants are effective, usually hydrogen cyanide. Owing to the potential danger and the elaborate precautions required, this type of fumigation has virtually ceased.

(ii) *Fumigation under fabrics*

In another type of fumigation, the gas is retained under plastic sheeting and this method is still widely practised for treating heaps of grain or other food products. Small (300 cu ft) tents for this purpose are available, costing about £60.

In the public health field, the method was represented by a device for delousing uniforms, used by American forces in the Second World War.<sup>(42)</sup> The clothing was put into a gasproof bag and a glass vial of methyl bromide broken inside it. This method has been revived for disinfesting clothing of lousy individuals at cleansing stations, prisons, etc., using ethyl formate.<sup>(15a)</sup>

(iii) *Van or chamber fumigation*

A third method of fumigation involves the use of specially constructed fumigation chambers. Mobile fumigation vans are convenient for disinfestation of bedding and other household effects. In Britain, fumigation vans have been largely employed for destruction of bed bugs, in connection with slum-clearance schemes; in addition, these vans can be used to eradicate fabric pests and furniture beetles.

The fumigant is usually introduced into the chamber in liquid form, usually on

to an electrically heated pan to volatilize it. Provision is generally made for an air circulation system, to distribute the gas rapidly and evenly. By suitable design, the fan and duct system used to circulate the air can be diverted to extract the gas after fumigation and blow it up an exhaust chimney.

This type of van has been used for many years with hydrogen cyanide and, more recently, with methyl bromide.<sup>(12)</sup>

(iv) *Small-scale box or bin fumigations*

Where articles require speedy disinfestation (e.g. clothing infested with clothes moths or by lice or fleas), they may be fumigated in a reasonably air-tight trunk or in a metal bin, such as a clean empty dustbin. Liquid fumigants with relatively high volatility are necessary and, for unskilled users, one that is safe and pleasant to handle should be chosen. For examples, ethyl formate, methyl formate or methyl allyl chloride can be used, at the rate of 300 cc per cubic metre, with an exposure of 5 hours. On such a small scale, it is easy to avoid danger from fire risk when using the formates. The temperature should preferably be 20°C or above.<sup>(15a), (20)</sup>

(v) *Use of solid fumigants*

Crystals of solid fumigants such as naphthalene or paradichlorobenzene may be scattered among woollen goods before storage, to destroy any eggs or larvae of clothes moths or similar pests which might be present. The fabrics should be stored in reasonably air-tight receptacles such as trunks or suitcases. In addition, the use of a suitable container (e.g. plastic bag) will prevent entry of moths or carpet beetles, so that, after the initial treatment, the goods remain free from attack.

Large articles such as carpets may be rolled or folded up tightly with crystals between the layers. In this case, naphthalene should be used as it is less volatile than paradichlorobenzene.

(vi) *'Residual' fumigation*

A new interest in fumigation for pests of medical importance was provided by the compound dichlorvos, which is so highly insecticidal at low concentrations that susceptible insects such as mosquitoes or flies are killed in a normal unsealed room (provided that ventilation is not excessive) by vapour emitted from one or more dispensers.

*Uses*

The first experimental uses of residual fumigation were as follows:

1. In trials connected with malaria eradication, the introduction of one or more dichlorvos dispensers in African native dwellings have given fair control of mosquitoes for about four months.<sup>(34)</sup>
2. Dispensers hung in drain sumps in Georgia, U.S.A., have given two months' control of nuisance mosquitoes, which breed in them.<sup>(47)</sup>
3. Special mechanical dispensers have been used successfully for aircraft disinsection.<sup>(60)</sup>

### Equipment

*Ordinary dispensers.* Two types have been used, both allowing the dichlorvos to diffuse from them. In one form the dichlorvos (40%) is fused with montan wax and moulded into cylinders ( $1.5 \times 5$  in.). In another form of dispenser, the dichlorvos ( $\frac{1}{2}$  oz: 14 gm) is put into a plastic bottle ( $1 \times 2.25$  in.) closed with a plug. This is wedged into a plastic sheath permeable to dichlorvos. On squeezing the unit, the plug is ejected from the inner container and the dichlorvos begins slowly to diffuse through the sheath.

*Mechanical dispenser.* A miniature air compressor drives air slowly through a porous membrane impregnated with dichlorvos. The air stream containing the vapour is then distributed as required; e.g. through the vents in the ventilating system of the passenger cabin of an aircraft. Operation of this unit for half an hour should secure disinsection.

## IV · INSECTICIDE RESISTANCE

### (a) Nature of resistance

The very wide use of modern insecticides, beneficial in many ways, has had some undesirable consequences. One of these is the emergence of resistant strains due to widespread and persistent destruction of normal insects, while abnormally tolerant ones manage to survive. In some circumstances this has resulted in the proliferation of abnormally resistant forms, which tend to replace the normal population. Emergence of resistant strains, then, is a selection of pre-existing genetic types, analogous to the selection of new varieties and species in natural evolution. The idea that resistance can be developed in individual insects, after exposure to sub-lethal doses, is a misconception.

### (b) Growth and importance of resistance<sup>(15)</sup>

Prior to the Second World War, resistant strains were rare curiosities, because, until the introduction of modern synthetic insecticides, the attack on insect pests by toxic chemicals was very rarely on a scale sufficient to exercise appreciable selective effect on natural populations. Beginning with DDT-resistant flies in 1947, however, the phenomenon has appeared in pest after pest, all over the world, until now well over 100 species are involved. In the field of public health entomology, resistance had been reported in 71 species by 1961, a serious blow to the control of insect-borne diseases, especially in the tropics. Among the disease vectors involved, apart from the housefly (which may carry enteric and ophthalmic infections) there are about a dozen anopheline mosquitoes (malaria), various culicine mosquitoes, including *Aedes aegypti* (yellow fever), the louse (typhus), various fleas (plague) and also pests of hygiene such as the bed bug and cockroach.

As far as Britain is concerned, the situation is much less serious.<sup>(14)</sup> This is partly because insect-borne diseases are rare here, but also because insecticides are used on a smaller scale and less frequently and systematically. In 1961, an inquiry sent to health inspectors in England elicited 13 reports of resistance among 186 replies. A similar inquiry to pest control companies yielded 14 reports in 23 replies.

Definite evidence of resistance seemed to be confined to houseflies (usually at treated refuse tips) and German cockroaches (mainly at ports). There was no other uncontrovertable evidence of resistance, despite the very great reduction in bed bugs, fleas and lice in this country, which has been largely achieved by the use of modern insecticides.

### (c) Counter-measures against resistance

The World Health Organization is much concerned about the problem of resistance and has taken the lead in co-ordinating counter-measures against it, largely through the agency of the Expert Committee on Insecticides. These measures can be conveniently grouped under the headings 'Information' and 'Research'.

#### (i) *Information*

It was soon realized that, for a proper evaluation of field reports of resistance, there was a necessity for standard methods of detecting and measuring resistance. Accordingly, standard test methods, suitable for field use, have been devised for many insects of public health importance, the details being published in successive reports of the WHO Expert Committee on Insecticides.<sup>(72)</sup> Each test method undergoes thorough examination by experts in different countries, both in the laboratory and in the field, and proceeds up the scale from 'tentative' to 'provisional' and finally to standard test method, if satisfactory.

Standard tests are available for mosquitoes (adults and larvae), lice, fleas and bed bugs. A provisional method is described for tsetse flies, etc., and tentative methods suggested for houseflies, ticks, cockroaches, etc. The tests for mosquitoes and lice have been in wide use for some years; they were developed early, because of the vector potential of the insects concerned. The other tests were more recently introduced and have been less widely used.

Complete kits for conducting the various tests are assembled by WHO in Geneva and sent to people conducting control campaigns against insects of public health importance in various countries. Results of the tests are sent back to Geneva, where they are recorded and analysed. Every two months, the WHO issues a circular of information on the resistance situation throughout the world and of current research on the problem. About every two years, recommendations of methods for vector control are issued, amended in accordance with the resistance situation.

#### *Various test methods*

It is not feasible to give a full description of all WHO test methods here and anyone intending to conduct such tests should obtain the latest report of the Insecticide Committee. A brief description, however, may be of interest to indicate the type of operations involved.

The following principles underlie all the tests. The susceptibility levels of the normal population of any species is first determined, by collecting batches of insects from the field and exposing them to a range of insecticide concentrations. After a suitable interval, the proportions killed are determined and plotted against the concentrations (on special graph paper). From the concentration/mortality graph, the

'median lethal concentration' (LC<sub>50</sub>), or average lethal dose, is estimated and the dose expected to kill all members of the batch is noted. These data are obtained on several occasions to take into account the normal variation of susceptibility in insects, due to environment (especially temperature). Finally, a dose rather higher than that expected to give complete kill is selected for routine checks for resistance. Survival in such checks is a danger signal, calling for further tests to confirm the existence of a resistant strain.

### *Test for resistance in adult mosquitoes*

The insects are collected by sucking tube and held in batches of about twenty in paper-lined plastic cylinders (Fig. 13). These cylinders, closed by removable slides, are then attached to similar containers lined with insecticide-impregnated paper. The slide is temporarily removed, the mosquitoes blown into the exposure cylinders and left there for an hour. The process is reversed and the mosquitoes left in the clean 'holding cages' for 24 hours before mortality counts.

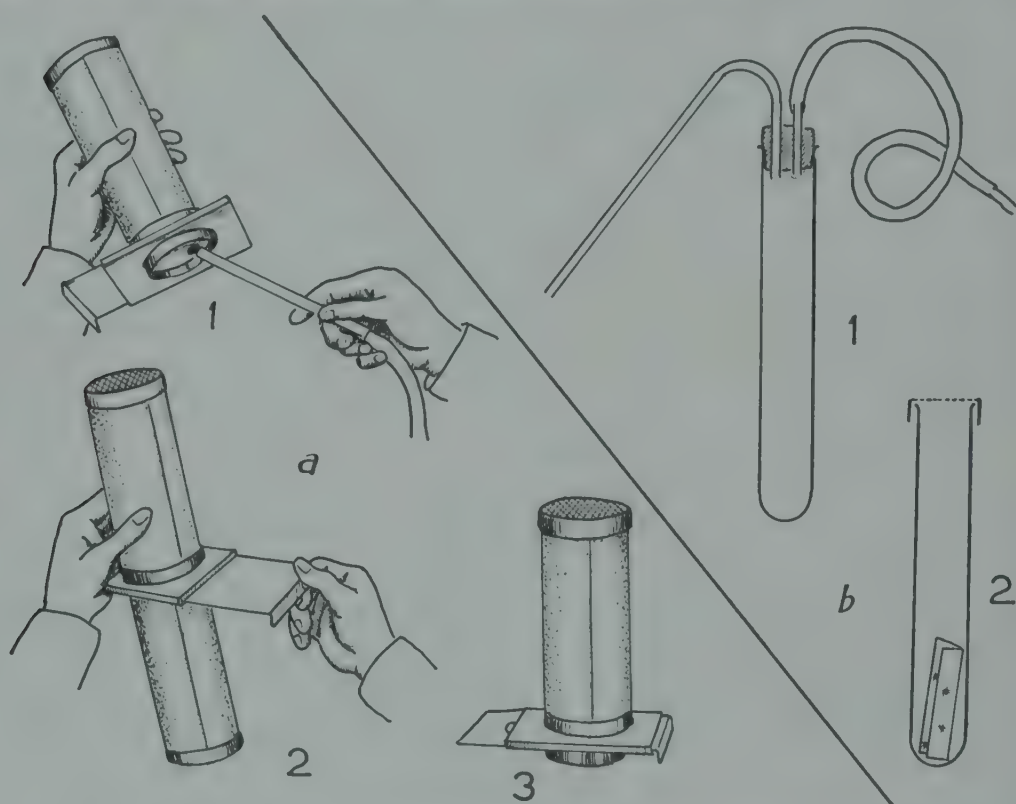


FIG. 13. World Health Organization standard tests for insecticide resistance.

#### *Left (a) for mosquitoes:*

- a 1. Mosquitoes collected by sucking tube are put into holding tube.
- a 2. Holding tube is screwed on to exposure tube, slide removed, insects blown into exposure tube and slide removed.
- a 3. Exposure (with holding tube removed). Afterwards, holding tube re-attached and procedure reversed to transfer mosquitoes to it, until examination for kill.

#### *Right (b) for fleas and bed bugs:*

- b 1. Test tube, with sucking attachment to collect fleas. (Bugs collected by forceps.)
- b 2. Exposure, with insects on folded, impregnated paper.

*Test for resistance in larval mosquitoes*

Well-grown (fourth stage) larvae are collected, divided into batches and put into large beakers (or jars) containing various dilutions of insecticide suspension. These are prepared first, by adding a small quantity of alcoholic insecticide solution to a rather large quantity of water. The larvae are left in the suspension for 24 hours before mortality counts.

*Test for resistance in body lice*

Lice are collected from infested people, divided into batches and confined on pieces of cloth which have been dusted with powder insecticides at different rates. Mortalities are estimated after 24 hours' exposure.

This test might be suitable for head lice; but no data are available.

*Tests for resistance in fleas and bed bugs*

Bugs are collected with forceps, fleas with a special sucking tube (Fig. 13). Both insects are exposed in the same way, on pieces of insecticide-impregnated paper in test tubes. For fleas, an exposure of one hour followed by 24 hours in a clean tube before examination is required. Bed bugs, however, must be exposed for 24 hours to organo-phosphorus insecticide, 2 days to dieldrin or 5 days to DDT.

*Test for resistance in cockroaches*

Deposits of insecticide are applied to the inside of 1-pint glass jars, by adding a small quantity of insecticide dissolved in a volatile solvent and rotating the jars on their sides until the solvent has evaporated. Cockroaches are put in the jars and kept in by a ring of grease round the mouth. They are observed at intervals until the insecticide paralyses them. The degree of susceptibility (or resistance) is indicated by the times for 50%, and for complete, 'knock-down'.

*Test for resistance in houseflies*

Since flies can be easily reared in the laboratory, there is less need for a field test for resistance than for other pests. Indeed, much research on resistant flies had been done before WHO methods became available. Thus, even by 1963, no single test method for flies had been agreed, though two tentative methods were published. Both are somewhat elaborate and the following simple method (rather similar to the cockroach test) is suggested by the author as a workable compromise.

Flies are collected by net and kept in small cages before use. It is preferable to use only females in the tests as they are more robust and less likely to be harmed by handling. The sexes can be readily separated after the flies have been stupefied by carbon dioxide or by chilling. They can be distinguished, with a little practice, by the width of the frons (between the eyes), which is much broader in the females than in the males; or by the dark spot near the anus on the underside of the abdomen of the males only.

The flies are exposed in 1-pint glass jars treated with 2.5 ml of one of the following solutions: 0.1% DDT; 0.1% technical dieldrin; 0.1% malathion; or 0.1% diazinon. The volatile solvent is evaporated by rolling the jars on their sides. An

hour or two later, about twenty flies are introduced under each inverted jar and the numbers knocked down recorded at intervals till all are recorded. From a graph relating percentage knock-down to time, the 50% and 100% paralysis times are estimated.

All normal flies should be paralysed in 1 hour except with dieldrin, which requires 2 hours.

### (ii) *Research*

Various kinds of research are involved. Toxicological investigations (i.e. measurements of resistant levels, especially to a variety of insecticides) have defined the various distinct types of resistance and their cross-resistance patterns (or 'resistance spectra'). Biochemical investigations have revealed some of the defence mechanisms which protect the immune strains. Genetical studies assist our interpretation of the spread, persistence and decline of resistant strains in populations of insects.

#### *Toxicological research*

True physiological resistance was soon found to be rather specific to a particular type of poison, giving more or less protection to related compounds, but not usually against different types of insecticide. The following forms of resistance are known:

1. Resistance to DDT, methoxychlor, etc.
2. Resistance to *gamma* BHC, toxaphene, dieldrin and other cyclodiene insecticides.
3. Resistance to organo-phosphorus compounds.
4. Resistance to carbamates.
5. Resistance to pyrethroids.

Types 1 and 2 have been known for some years; they are common and have been the subject of much research. Type 3 is less familiar, but a fair amount has been discovered about its nature. Types 4 and 5 are still less common and little understood; 4 is sometimes combined with 3, while 5 is (curiously enough) often associated with 1.

#### *Biochemical research*

Detoxication of the poison by enzymatic breakdown in the insect's tissues is one important defence mechanism against DDT, the organo-phosphorus compounds and, probably, the carbamates. The mechanism of type 2 resistance is little understood. It is not a detoxication mechanism and is probably due to a change in the vital centre normally sensitive to this type of poison.

#### *Genetical research*

The mode of inheritance of resistance has been extensively studied. Nearly always, resistance is inherited through normal Mendelian genes, usually a single pair. Individuals carrying such genes are normally rare in the insect population, until the wide use of insecticide promotes their survival value. The speed with which a

resistant strain will emerge depends on (1) the presence of resistant genes in the original population, (2) the intensity of selection (i.e. the more widely and regularly the insecticide is used), and (3) whether the genes are dominant, intermediate or recessive. Dominant or semi-dominant genes obtain the benefit of their protective mechanism in the heterozygous condition and so they rapidly build up into a resistant strain as soon as insecticide is used. Recessive genes confer no advantage except in the homozygous condition, which is very rare when the gene is infrequent. Hence recessive resistance (e.g. DDT resistance in mosquitoes) is slower to develop than dominant forms (e.g. most examples of dieldrin or organo-phosphorus resistance).

If the selecting agent is removed (i.e. the use of a particular insecticide is abandoned) the resistant strain no longer dominates the population. Unfortunately, however, the genes take a very long time to recede to insignificant levels; and during this long period, any renewed use of the insecticide rapidly brings the resistant strain to the fore.

#### (d) Preventing or overcoming resistance

Unfortunately, there is no known way of deriving the benefits of the new insecticides without some risk of provoking resistance. The following points, however, deserve some consideration.

##### (i) *Preventing of resistance*

It is, perhaps, unwise to use insecticides regularly on a wide scale, unless some vital object is to be attained, such as the total elimination of the pest or some insect-borne disease. The possibility of causing resistance must be borne in mind, therefore, if any large insecticide campaign is being planned.

From time to time, people have suggested the possibility of using mixtures of two different types of insecticide or, alternatively, of using them one after another, with the intention of preventing resistance. Unfortunately, this is not really justified theoretically, nor does it seem to succeed in practice. The only possible chance of success would be if two poisons could be found, of which one was most toxic to the individuals most tolerant of the other. Despite some early hopes, however, no such ideal combinations have been discovered.

##### (ii) *Overcoming resistance*

Alternative methods of insect control (especially improved hygiene) should be used instead of, or together with, insecticides. This is something that can be done now; other measures depend on the progress of research.

A continual search for alternative insecticides is going on, one international programme in this field being sponsored by the WHO. In addition, it is always possible that the fuller understanding of the biochemical mechanisms responsible for resistance may enable us to circumvent it. For example, the addition of suitable synergists to certain insecticides may overcome resistance. This possibility has shown some promise, though it is not yet a practical proposition.

## V · TOXIC HAZARDS OF PESTICIDES<sup>(2, 37, 49)</sup>

At the beginning of this chapter it was stated that, with the progress of science, the old inorganic poisons which are toxic to all forms of life were being replaced by synthetic organic insecticides specifically toxic to arthropods rather than to man and higher animals. Yet, sparked off perhaps by Rachel Carson's *Silent Spring*, there has been more concern about toxic hazards in the 1960s than ever before. There are two possible justifications for some of the present anxieties. One is the enormous growth in use of pesticides and the other is the great chemical stability of some of them, resulting in very persistent residues.

For a proper understanding of the possible dangers involved, it is important to distinguish between the entirely different hazards of *acute poisoning* (due to a single large dose) and *chronic poisoning* (due to constant exposure to small doses).

### (a) **Acute toxicity of insecticides**<sup>(26, 30, 43)</sup>

#### (i) *Types of hazard*

The dangers of acute poisoning, by ingestion or contamination by a single large dose of insecticide, are relatively small and comparatively easy to assess.

It is generally recognized that many substances in daily use (coal gas, disinfectants) involve some risk of misuse. In the same way, insecticide concentrates (including their solvents) may be dangerous to careless handlers, to children and to potential suicides. There is, however, no doubt that the numbers of fatalities from this cause are small, as indicated by the deaths *from all solid and liquid poisons* in the U.S.A. (in 1956):

Deaths, all causes	935	per 100,000
„ from accidents	58	„ „
„ from poisons	0·9	„ „

#### (ii) *Assessment of acute toxicity*

The danger of acute intoxication from swallowing various insecticides can be judged from laboratory experiments with animals. Since tolerance varies to some extent in different species, the most reliable estimates of possible danger to man are based on tests with different animals, preferably including monkeys. For convenience, however, most preliminary data are obtained with white rats. Table 7 gives an indication of acute toxicity hazards by comparing oral toxicity to rats with the insecticidal potency (to flies) of various compounds. It will be seen that the majority are much more toxic to the insect than to the mammal.

#### (iii) *Selective toxicity to insects*

High toxic substances are usually compounds which seriously interfere with some vital physiological function. Unfortunately, most essential biochemical processes are common to arthropods and vertebrates, so that it is not easy to find chemicals which are toxic to the former and completely innocuous to the latter.

TABLE 7 *Acute toxicity of various insecticides to the rat and to the housefly*

Data for the rat from various sources;<sup>(26, 43, 30)</sup> data for the housefly original.

As regards acaricides, the following acute LC<sub>50</sub> values for rats have been reported (mgm/kgm): benzyl benzoate, 2650; chlorobenzilate, 700-3100; chlorbenside, 2000; chlorbensone, 2000; dicofol, 575-1100.

	LD50: mgm/kgm				LD50: mgm/kgm		
	Oral		Contact		Oral		Contact
	Rat	Rat			Fly	Rat	
Pyrethrins	570-1500	>1880	22	parathion	3-6	7-200	3.2
Allethrin	700-1000	—	34	EPN	8-17	25-230	4.0
Lethane	100-250	—	200	trichlorphon	560-630	>2000	11
Thanite	1000	—	400	coumaphos	16-150	860	6.8
DDT	115-250	2500	18	dichlorvos	25-80	75-900	1.7
DDD	2500	—	44	diazinon	76-600	455-1200	6.5
methoxychlor	6000	6000	24	malathion	1000-1900	>4000	50
'Dilan'	4000	6000	—	fenthion	200-245	300-1300	1.7
gamma BHC	90-225	500	1.0	fenchlorphos	1250-2630	—	8.2
toxaphene	80-283	>1000	30	dimethoate	200-300	400-1150	1.1
heptachlor	40-162	200	1.3	Chlorthion	880-980	1500-4500	20
chlordane	283-430	>1600	4.0	fenitrothion	250	>3000	6.6
aldrin	39-60	>200	1.9	naled	430	1100	0.1
dieldrin	40-46	>100	1.2	phorate	1-3	3-300	15
endrin	3-18	90	1.8	Dicaphon	330-400	800-1250	3.8
isobenzan	6-10	5-30	0.9	carbaryl	400-850	>4000	245
endosulphan	18-43	74-130	6.6	dimetan	150	—	290
				dimetilan	25-50	600-700	9.8
				Pyrolan	50-60	—	114

Nevertheless, some degree of specific insecticidal action may be obtained as follows.

(1) Some compounds, such as DDT, owe their comparative safety to their inability to penetrate the human skin (even when undiluted) while they readily pass through the insect's cuticle. Entry of DDT into mammals is facilitated, however, if it is in an oily solution and in this form it is much more easily absorbed from the alimentary canal.

(2) Other compounds may be more easily detoxified in mammalian tissues than in insects, e.g. pyrethrins. The organo-phosphorus esters vary in their relative stability and, by appropriate selection, some have been found which are relatively much more stable in tissues of insects than mammals and thus constitute safe insecticides (e.g. malathion, fenchlorphos, etc.).

Here again, a warning is desirable. Certain organo-phosphorus compounds rapidly inactivate the enzymes which detoxify others, e.g. traces of EPN, dichlorvos, etc., greatly increase the mammalian toxicity of the normally safe malathion. This effect, known as *potentiation*, demands caution in possible mixing of such insecticides.

(iv) *Toxic action, signs and symptoms*<sup>(65)</sup>

Metallic salts of arsenic, mercury and thallium, as well as the inorganic fluorine compounds, are cell poisons with deleterious effects on many enzymatic processes in different tissues. The more advanced organic insecticides, however, are practically all specifically toxic to nerve cells and are usually without effects on other tissues and moderate doses. These nerve poisons all cause certain symptoms (headache, nausea, vomiting, dizziness) which are not specific and, indeed, can be due to causes other than poisoning. Accordingly, in the following sections, the characteristic signs and symptoms of intoxication by different insecticides will be stressed.

*The chlorinated insecticides*

There are certain distinct differences in the mode of acute intoxication by DDT and its analogues on the one hand and *gamma* BHC and the cyclodiene insecticides on the other.

DDT is known to act preferentially on sensory nerves and appears to cause unstabilization of the polarization of the nerve axons, so that nerve impulses tend to be reduplicated. As a result, both insects and mammals show the effects of overstimulation causing continual tremors and muscular inco-ordination. One of the symptoms characteristic of DDT poisoning is paraesthesia (numbness, tingling) of the mouth, part of the face and, in severe cases, the extremities.

Less is known about the mode of action of *gamma* BHC and the cyclodiene series, the site of action of which appears to be in the central nervous system. Mammals poisoned by these compounds tend to show hyper-excitability and later suffer severe clonic and tonic convulsions, even in non-fatal cases.

*Organo-phosphorus and carbamate insecticides*

Considerably more is known of the mode of action of this group of insecticides, which act as anti-cholinesterase poisons, both in mammals and in insects (see pp. 105-107). Accordingly, the more characteristic signs and symptoms of intoxication are those due to excessive acetylcholine. In mammals these can be recognized by excessive stimulation of the parasympathetic system. There is contraction of the pupils, profuse secretion of saliva and tears, diarrhoea, discomfort in the chest (due to constriction of the branchioles) and retardation of the heart. Additional symptoms, which are not so specific, include headache, nausea and blurred vision.

(v) *Prevention and treatment of poisoning**Prevention*

Acute poisoning by insecticides is more common in children than in adults and the obvious precautions regarding any poisons should apply. In particular, insecticide concentrates should not be transferred to unlabelled bottles or tins and empty containers should be disposed of safely.

It may be remarked that most deaths are still caused by old-fashioned insecticides like arsenic rather than the newer insecticides.

*Treatment*

Only the simplest remedial measures can be attempted by a non-medical person, the main one being to remove the poison as soon as possible. For a poison taken internally, an emetic may be given or, as a first-aid measure, vomiting induced by a finger down the throat. Evacuation of the gut is desirable, avoiding oily laxatives especially where chlorinated insecticides may have been taken.

After external contamination, thorough washing of the eyes or body is advisable. Artificial respiration, preferably by mechanical means, may be required for patients who have collapsed after organo-phosphorus poisoning. Medical treatment in many cases must be symptomatic, in view of our ignorance of the mode of action of many insecticides, e.g. the use of sodium pentobarbital as a rapid sedative to combat hyper-excitability or convulsions. Intoxication by the anti-cholinesterase insecticides may be more scientifically treated by atropine sulphate (1 to 2 mgm) which antagonizes acetylcholine.

**(b) Chronic toxicity of insecticides***(i) Types of hazard*

There are two distinct risks of chronic intoxication by pesticides. One concerns the pest control operator who regularly sprays or dusts insecticides. This is a very real hazard, though it is one which can reasonably be assessed and with proper precautions, overcome. It often relates to skin contamination, though food or cigarettes may carry the poison to the stomach also. Considerable information on the subject is available as a result of the numerous anti-malarial house-spraying campaigns all over the world. In this work, no trouble was encountered in spraying DDT or *gamma* BHC, but there have been a number of cases of poisoned men who sprayed dieldrin.

The other risk is the regular ingestion of small traces of pesticide in the food, and this may affect any member of the population. Excluding gross and abnormal contamination of foodstuffs, there is evidence that the normal use of insecticides has resulted in nearly all people acquiring small residues of chlorinated insecticides (4 or 5 ppm in the body fat of American people). On the other hand, people with ten times as much in their bodies have shown no apparent harm.

*(ii) Assessment of chronic toxicity<sup>(22, 37)</sup>*

It is very difficult to assess the possible harm from low-level absorption of insecticides. Gross effects can be judged from animal experiments, but even these are slow and difficult. An approximate idea of relative harmfulness can be gained from the following minimum dietary levels (ppm) causing gross pathological changes in rats:

DDT	100	malathion	>5000
DDD	2500	Chlorthion	>5000
methoxychlor	5000	dichlorvos	>1000
<i>gamma</i> BHC	400	diazinon	1000
dieldrin	25	EPN	25
chlordane	250	parathion	50

It will be noted that the organo-phosphorus compounds, though more acutely toxic, are less chronically harmful than the chlorinated insecticides. Presumably they are less stable, in small amounts, in body tissues.

### (iii) *Prevention of chronic intoxication*

Prevention of chronic poisoning of spray men by insecticides consists in: (1) precautions in handling and mixing insecticide concentrates, including the wearing of rubber gloves if the hands are likely to be contaminated; (2) wearing of protective clothing (see Fig. 12g); (3) changing clothes and bathing after work.

Medical officers or others responsible for spray teams should study the matter carefully.

In regard to toxic residues in food, the Medical Research Council Toxicology Committee recommend that the following levels should not be exceeded: 7 ppm DDT; 2.5 ppm *gamma* BHC; 8 ppm malathion.

One possible source of contamination of foodstuffs is the aerosol from electrically operated thermal generation (see p. 130).<sup>(3)</sup> There are no official recommendations of safe limits published in the U.K., but an American committee has recommended that the output of DDT or *gamma* BHC by these generators should not exceed 67 mgm per day per 1000 cu ft.

### (c) **Allergic reactions to pyrethrum**

Of the insecticides in common use, pyrethrum is one of the least toxic, since it is readily decomposed in the intestine and other tissues of mammals. On the other hand, it may cause contact dermatitis, especially in sensitive individuals, apparently due to an allergic reaction. The usual picture is a mild erythematous, vascular dermatitis, with papules in moist areas, and intense pruritus. A bulbous dermatitis may develop and some individuals develop signs and symptoms similar to those of hay fever.

Positive patch tests with pyrethrum extract are helpful in diagnosis. Treatment is symptomatic, anti-histamines being of value in many cases.

### (d) **Toxic hazards to animals**

#### (i) *Domestic animals*

There are not infrequent reports of cats being poisoned, and even dying, after dwellings have been sprayed with insecticide. It is not known exactly how they picked up the poison, but one possibility is contamination of the fur, which would be licked clean by a cat.

#### (ii) *Wild life*

Some concern has been felt at the possible danger to wild life (especially rare predaceous birds) by widespread agricultural use of insecticides. The matter has been reviewed by committees of the Agricultural Research Council<sup>(2)</sup> and of the Ministry of Agriculture, Fisheries and Food.<sup>(49)</sup>

There seems to be only one usage of insecticides, against insect pests of public health importance, which involves possible harm to wild life. This is the application of mosquito larvicides to natural waters, which might be harmful to fish if they are

present. The available data suggest that the following are safe limits of application, in lb per acre, of various insecticides, unlikely to harm fish: malathion 0.5; fenthion, 0.2; DDT, *gamma* BHC and parathion, 0.1; dieldrin, 0.05. (N.B. 0.1 lb/acre is equivalent to 11.2 mgm per sq m.<sup>(11)</sup>)

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## 8 · Houseflies and blowflies

### I · INTRODUCTION

The order Diptera, of two-winged flies, is of prime importance in medical entomology, containing as it does bloodsucking forms, disease vectors and various nuisances. It is a large and successful insect group divided into three sub-orders at different evolutionary levels: Nematocera, Brachycera and Cyclorrhapha. The first appears as fossils in the Permian while the other more advanced groups do not appear till the early Tertiary.

*Nematocera* are generally slender fragile flies, with long antennae composed of many similar segments and palpi of several joints. The larvae, usually active, with well-developed heads, live in water or damp soil. They include the biting gnats and midges discussed in Chapter 9.

*Brachycera* are usually large flies with short antennae, projecting forward, and two-jointed palpi. Only one family, the horseflies, is of medical importance and it is considered in the next chapter, on bloodsucking flies. The larvae have reduced heads and live in damp soil or water.

The *Cyclorrhapha* is the most advanced group, mostly comprising flies of compact build, often bristly. The antennae consist of three joints lying down in front of the face, with a large bristle (the 'arista') on the last segment. The palps are single-jointed.

The larvae are headless maggots, devoid of eyes or other complex organs of special sense, living in and feeding on decaying organic matter. Pupation in this group always occurs within the last larval skin, which remains to protect the pupa as a small barrel-shaped cover. When the fly emerges, it pushes off the top of the 'puparium' which splits along a circular line (giving the Greek derivation of the name *Cyclorrhapha*).

The *Cyclorrhapha* contains a number of families mainly of small flies rather difficult to define and two distinct important families: the Muscidae or houseflies and Calliphoridae or blowflies. These flies may be annoying or directly harmful to man and sometimes act as vectors of disease.

Their habit of breeding in putrefying matter has led many flies into an interesting and sometimes important association with various animals (wild and domesticated) and with man.<sup>(9, 51)</sup> Possibly, the original breeding material of most flies was decaying vegetation, but many of them have adopted the habit of breeding in the faeces of various animals, while others develop in decaying carcasses. Such materials are rich in nitrogenous matter, to digest which the larvae have evolved suitable enzymes. They also have the ability to rid themselves of excess nitrogen by excreting gaseous ammonia.<sup>(1)</sup> The adults of these scavenging forms usually lay large batches of eggs on suitable material and the larvae emerge to browse in it. In addition, there are

certain species with specialized habits, some of them attacking and eating the scavenging larvae and others with unusual parasitic larval stages.

The coprophagous species show more or less preference for certain types of dung (the preference being exercised, of course, by the mother fly, seeking suitable food for her progeny). The quantity and condition of the breeding material is also important; some species breeding in isolated dejecta in the fields, while others prefer the large masses of dung piled up in farmyards or accumulations of domestic refuse.

The flesh-feeding species breed mainly in carrion, but in some cases eggs are laid on festering sores or excrement-soiled parts of living animals. The maggots then develop in the living flesh and on some occasions may develop such a large wound that the infested animal is killed. (This is what occurs when sheep are 'struck' by the blowfly *Lucilia*.)

The feeding habits of many adult flies extend further their association with domestic animals and man. Most of them require carbohydrates and water for their active flight and, in addition, the females require nitrogenous matter for maturation of their eggs. In many species the females feed exclusively on dung; these are usually of no practical concern to man. But others are more catholic in their tastes and will feed on many other substances. The housefly (*Musca domestica*) is an outstanding example of such a polyphagous feeder; it will feed equally upon excrement and many human foodstuffs. Other flies associate with beasts in the fields and alternate between feeding on dung and liquid secretions from the animal body such as perspiration and the moisture of various mucous membranes (eyes, nostrils, etc.). Several species will readily feed on blood exuding from wounds even from the small pricks made by biting flies. Finally there are certain species, with mouthparts specially modified for piercing the skins of warm-blooded animals, which feed exclusively on blood in the adult stage.

From the human point of view the scavenging habits of many higher Diptera are not unsatisfactory in that they accelerate the decomposition of the excreta and carcasses of higher animals. On the other hand, the habits of a proportion of them result in more or less serious nuisances, either due to the larvae or the adults. The maggots of some species cause trouble when they occur in food (especially if they are swallowed alive) or in wounds or cavities of the animal body. The adult flies may be vexatious in several ways. A few of them suck blood and their bites may cause irritation to man or domestic animals (stable fly, etc.). Some may act as disease vectors, either by polluting food after visiting faeces (houseflies), contaminating mucous membranes after visiting festering sores (houseflies in the tropics) or by injecting infected saliva in the bloodsucking forms (tsetse fly). Furthermore, the mere presence of large numbers of flies indoors is regarded as very unpleasant by most civilized people.

Although several potentially dangerous flies occur in Britain, the more serious of these troubles are fortunately rare, owing to generally high standards of hygiene combined with a cool climate. The flies that may be encountered indoors in Britain can conveniently be divided into two groups, (a) those which are likely to be encountered as adults and (b) those likely to be troublesome in the larval stage.

In this chapter, group (a) will be considered in the following sections: II The

housefly, III The lesser housefly, IV Swarming houseflies, and V Flies from sewage works. Group (b) will be treated under sections VI Blowflies, VII Myiasis, VIII Fruit flies, IX Phoridae, and X The cheese skipper.

## II · THE HOUSEFLY (*Musca domestica*)

The housefly is world-wide in its distribution and everywhere lives in close association with human dwellings. There are, however, slightly different races living in temperate, warm and hot climates; the characteristic forms being known as *M. domestica domestica*, *M. domestica vicina* and *M. domestica nebulo*, respectively. They differ in depth of coloration (darkness being associated with cool conditions) and the width of the 'frons' between the eyes of the male. These forms are not separate species; they intergrade, and even the extreme types are quite inter-fertile. Observers have noted somewhat different habits of flies in the tropics. For example, they rest out of doors at night and they are more prone to visit and breed in human faeces, if accessible. Yet one cannot say whether these differences are innate, or whether they represent a similar reaction to different environments.<sup>(41)</sup>

### (a) Historical notes

It may be remembered that a visitation of flies constituted the fourth of the plagues of Egypt; certainly the housefly has been a constant companion of man since remote times. A late medieval reference to houseflies is contained in the *Menagier de Paris*, written by an unknown Parisian in 1392-4. To rid a room of flies he suggests '... shut up your chamber in the evening, but let there be a little opening in the wall towards the east, and as soon as the dawn breaketh, the flies will all go out through this opening and then let it be stopped up' (Eileen Power's translation, Routledge, London, 1928).

### (b) Distinctive characters

The common housefly is usually about 6-7 mm long, with a wing span of 13-15 mm. The thorax is grey with four longitudinal stripes, most clearly distinct in front (Fig. 14b). The fourth vein on the wing bends sharply forward and nearly meets the third vein at the wing margin. The sides of the basal half of the abdomen are yellowish buff and sometimes transparent, especially in the male. A central longitudinal band broadens at the back to cover the final segments.

### (c) Life history

#### (1) Oviposition

It is convenient to commence a description of the life history with the mature female seeking a suitable site to lay her eggs.

Flies will breed in a large number of substances (ranging from snuff to spent hops!) of which the only common factor seems to be a moist, fermenting or putrefying condition. Typical examples are (a) the excrement of various animals (pig, horse, calf, man), (b) rotting vegetable matter, especially with a high protein content (seeds,



FIG. 14. Some houseflies and blowflies. (a) *Calliphora erythrocephala* (the bluebottle); (b) *Musca domestica* (the housefly); (c) *Sarcophaga carnaria* (the flesh-fly); (d) *Fannia canicularis* (the lesser housefly); (e) *Lucilia sericata* (a greenbottle); (f) *Pollenia rudis* (the cluster fly); (g) *Muscina stabulans*; (h) *Stomoxys calcitrans* (the stable fly). All specimens are females with the heads of the males above. (After Graham Smith, *Flies and disease*, Cambridge University Press, 1913.) (a) (c)  $\times 1\frac{1}{2}$ ; (e)  $\times 2$ ; (f) (g)  $\times 2\frac{1}{2}$ ; (b) (h)  $\times 3$ ; (d)  $\times 3\frac{1}{2}$ .

grain), (c) decaying animal remains and (d) the heterogeneous mixture which constitutes garbage. Some types of breeding material are more favourable than others. The matrix must not be too dry or too wet; thus, on the one hand, horse droppings in the field are unsuitable since they soon become desiccated, whereas bucket latrines are too wet and seldom contain housefly larvae. Where the egg-laying female can exercise a choice (on a farm for example) she shows a predilection for certain kinds of dung. Horse dung is preferred if it is fresh but it rapidly loses its attraction. Pig dung is very attractive for a week or more and is a common breeding material. Calf dung is sometimes and cowdung very rarely infested.<sup>(27, 61)</sup> In cities there was formerly much breeding in manure stacks near stables, but such sites have very greatly diminished with the replacement of horse-drawn traffic by the motor-car. At present, fly nuisances in cities are mainly due to excessive infestation of municipal refuse tips or other large accumulations of decaying organic matter.

The females seek out suitable breeding material largely by olfactory organs which are located on the antennae. If these are amputated the females lose their discrimination between various breeding materials.<sup>(28, 51)</sup> There is also evidence that they confirm their judgement by tasting the material they have selected. The female flies usually prefer to lay eggs on breeding material exposed to light; they do not often fly into dark places in search of suitable sites. But having landed on the pile of material, they often crawl into small crevices and, by the use of their ovipositor, deposit the eggs still further into the mass. The value of this behaviour is probably that the eggs will be protected from desiccation by exposure to dry summer air.

During a single day a fly, if undisturbed, may lay the whole batch of eggs which are mature in her ovaries, usually about 100 to 150. This may be repeated four or five times at intervals during her adult lifetime.

#### (ii) *Egg*

In appearance the eggs of the housefly are rather like minute pine kernels; they are cylindrically oval, white bodies about 1 mm long. The incubation period varies from about 8 hours to 2 days, depending upon temperature, and there are a number of records available for different air temperatures. It should be remembered, however, that owing to fermentation, the matrix of the breeding material will be considerably warmer than the air.

When the embryological development is complete, a longitudinal split develops in the egg shell and the young larva emerges.

#### (iii) *Larva*

The young larva is repelled by light and burrows into the food material, which it consumes. As already mentioned, the putrefying substances in which fly maggots breed generate heat through bacterial action. In large heaps of manure or refuse a temperature of 70°C (158°F) is often reached, which is too high for insect life; but the temperature falls off towards the periphery. The maximum temperature and the steepness of the gradient depend on the nature and bulk of the fermenting material, the tightness of packing and the external air temperature. The fly maggots

choose a layer according to their preference which is remarkably high;<sup>(8)</sup> they are frequently found in manure or refuse at a layer where the temperature is 45–50°C (113–122°F). Under such conditions the larva grows quite rapidly and in the course of its larval life moults three times and there are three larval stages. These three stages are similar in general appearance and habits. The body consists of thirteen segments arranged to form a shallow cone (Fig. 16c). The mouth is at the point of the cone but there are no ordinary insect mouthparts (mandibles etc.); instead there is a pair of vertical black hooks inside the mouth which articulate with a small black internal skeleton. At the posterior end of the body are two spiracles which communicate with the simple respiratory system. These two spiracles, which are borne on small tubercles and are readily seen, are of considerable importance in identifying the maggots of different kinds of fly. The cuticle of the maggot is thin and flexible but it is fairly tough.

Towards the end of larval life, the maggot changes somewhat in colour, becoming creamy rather than white. This is due to the deposition of fat reserves in the body wall and to other internal changes. At this point the larva ceases to feed and leaves the hot, damp fermenting part of the breeding materials. Whereas the larva can live and develop satisfactorily at quite high temperatures, the pupal development must be passed in a cooler environment. If larvae are prevented from leaving the hot fermenting material there is a considerable mortality among the pupae at temperatures above 40°C (104°F).<sup>(9)</sup> A larva developing in a manure stack usually descends to the ground round the periphery of the heap where it burrows into loose soil. If the ground happens to be very hard the maggot sometimes wanders away as much as 50 yards in search of a suitable spot. Finally the larva prepares to pupate by contracting to a smooth ovoid shape and casting the last larval skin, which dries and hardens in this form. As it hardens, the old skin gradually darkens in colour to a deep chestnut brown. If fly-infested material is buried beneath a covering of earth, the larvae will usually burrow their way up until they are not far below the surface before pupation. To prevent their emergence the covering of earth must be thick (about 2 feet) and well consolidated.

#### (iv) *Pupa*

Inside the brittle ovoid skin cast by the larva and called the 'puparium' lies the pupa in which the rudiments of the anatomy of the adult fly can be discerned (Fig. 16f).

The very great reorganization of tissues necessary to change a larva into an adult are begun towards the end of larval life and they are carried to completion in the pupa.

When the adult fly is ready to emerge, it presses against the front of the puparium which splits in a perfectly regular manner characteristic of most higher types of Diptera. A circular split develops round at the level of the sixth segment and two lateral splits run forward from this, leaving a split cap at the front of the pupa case which is easily detached and leaves the way clear for the emerging insect.

During the emergence from the pupa case and from the earth in which it is usually buried, the adult fly makes use of a very peculiar organ on the head. This is an evertible bag on the head which arises from a crevice between the eyes. By

alternately inflating and deflating this tiny bag, the insect clears a course for itself through the loose soil. When it finally emerges to the air, the inflated bag (or 'ptilinum') is withdrawn into the head and is never used again.

(v) *Adult*

The relatively large wings of the adult fly are constricted by the pupal skin and, on emergence, are in a somewhat crumpled condition. One of the first acts of the young adult fly is to expand the wings so that it can fly. This is accomplished by the internal hydraulic pressure of the blood before the adult cuticle has hardened. Newly emerged flies can often be found on or near their breeding ground. Apart from the crumpled wings in process of expansion, they can be recognized by the pale colour of their not yet hardened cuticle. When the hardening process has finished, the fly has reached its final condition, no further growth is possible.

Some aspects of the fly's anatomy are important in relation to its habits and these will be briefly considered. The division of the body into head, thorax and abdomen is very obvious because of the marked constrictions separating them. The most prominent features of the head are the large compound eyes which contain about 4000 facets and testify to the relative visual acuity of the housefly. The antennae of the housefly, like those of other flies of this type, are reduced to short stumpy appendages consisting of two small and one large segment, the latter bearing a characteristic bristle.

The antennae, as already mentioned, carry olfactory organs which enable females to detect breeding medium and increase male reactions to female odour. In addition, both sexes are attracted by certain odours, presumably associated with food.<sup>(57)</sup> Most potent, in this respect, is a mixture of malt extract with addition of a little acetal, alcohol and skatole.<sup>(2)</sup> The olfactory organs of flies, however, appear to be less well developed than in related flies and blowflies. It has been suggested that the housefly, in its limited environment, has less need of acute olfactory perception than, say, the blowflies, which display astonishing powers of detecting carrion at a distance. The housefly seems to make up for its lack of olfactory perception by restless, inquisitive behaviour, combined with acute eyesight.<sup>(59)</sup> It is known to be attracted to objects surrounded by other flies (even dead ones).<sup>(60)</sup> This is not difficult to demonstrate.

It is not known whether flies can distinguish colours, though this faculty has been demonstrated in bees. There have been intermittent investigations of the 'colour preferences' of houseflies giving a rather confusing picture, since some of the conclusions appear contradictory. Perhaps the explanation is that flies are more sensitive to short wavelength light, so that blue appears brighter than red. A disturbed fly, seeking escape towards a light, will then choose a blue source; whereas flies allowed to settle quietly seem to prefer dark sites and often choose red in preference to other colours.

The mouthparts of the fly are so very highly modified from the primitive type that it is impossible to recognize their affinities by mere inspection. It appears that the lower lip (or labium) has become changed into a flexible proboscis. This proboscis is hinged in the middle so that the lower part can be either folded up or

extended downwards to probe the ground. The sides of the proboscis turn forwards to form a groove in which the food channel lies and the upper lip (labrum) with certain other elements, forms the roof of the groove. At the end of this apparatus are two sucking lobes, joined along the centre, each lobe being traversed by fine suction canals which collect liquid towards the central feeding channel. There are no mandibles or any other parts for piercing or biting so that it is clear that the fly can only feed on liquid food. If a fly is dissected it will be found that the food channel or pharynx, after entering the head, runs back through the neck into the thorax where it divides into two. The lower, more direct, branch continues backwards and leads to a blind sac, the 'crop', in the abdomen.

The upper branch, which begins with a muscular valve, continues as the main intestines, which lie coiled in the abdomen and finally communicate with the anus. Besides these organs there is a pair of long thread-like salivary glands lying in the body cavity and running forward to discharge into the food channel in the proboscis (see Fig. 6*d*).

The primary food needs of houseflies are carbohydrates (mainly sugars) for energy and protein, which the females especially require for egg production. Water is also necessary, particularly as flies salivate and pass liquid faeces. Sugar, however, is the most urgent need and flies die more quickly in its absence than when deprived of water. Convenient sources of sugar are found in human dwellings, which also provide sources of protein (e.g. milk). Many other substances may be visited and tasted by flies, such as fresh faeces and perspiration.

Curiously enough, the most important tasting organs of the fly are on its tarsi. A hungry housefly walking over sugar (especially if it is slightly moist) can immediately detect it and will extend its proboscis at once, to feed.

As already stated, flies can only swallow liquid food. They can, however, 'lick' over solid foods, using their salivary juice (and apparently also some regurgitated fluid from a previous meal) to liquify them. The liquid is drawn up the proboscis by sucking movements of part of the pharynx, and passes straight into the crop. If they are undisturbed, flies will feed until their crops are full to bursting point. Subsequently this liquid is regurgitated and appears as a large pendant drop from the end of the proboscis. Drops of liquid are slowly extruded and withdrawn several times and finally the liquid passes through the muscular valve into the main intestine for digestion. It seems quite possible that the object of this regurgitation is to discharge into the liquid a further quantity of salivary juice.

During the process of regurgitation, it quite often happens that a drop of the fly's vomit falls from the end of the proboscis to the surface on which it is resting. The marks of these 'vomit spots' can quite often be traced on places frequented by flies, together with darker specks that mark deposition of the fly's faeces. In addition to this way of contaminating their environment, flies defaecate very frequently; probably about every five minutes. This can be demonstrated as follows. Some well-fed flies are confined on clean paper in a Petri dish. After a few minutes this is held under an ultra-violet lamp and the paper will be seen to be covered with flecks of faeces, which fluoresce a bright blue colour, though scarcely visible to the naked eye.

The thorax of the fly is almost entirely devoted to locomotion. It is compact and rather robust and a dissection of this region reveals the relatively powerful muscles which activate the wings indirectly by distortions of the thoracic frame (see p. 38). These muscles constitute 10% of the weight of the body. In flight the wings are set beating at the rate of nearly 200 strokes per second. They beat downwards and forwards and then vertically (with edge uppermost) and move back. This motion supports the fly in the air and moves it forwards at the rate of four or five miles per hour.<sup>(31)</sup>

Entomologists are sometimes asked 'How far does a housefly fly?' It is as difficult to give a simple answer as it is to the question 'How far does an Englishman travel to work?' Actually, the distances might not be so very different! Numerous experiments have been made in marking flies (by dyes or radioactive traces), releasing them and attempting to recover them in traps. In various American trials, houseflies were captured up to 5 miles away, within 24 hours; and later up to 20 miles.<sup>(42)</sup> For practical purposes, however, the exceptional cases are much less important than the average; and it appears that the bulk of flies in towns are unlikely to move more than a mile or two from the breeding source. On the other hand, flies in open country will disperse more widely in search of human dwellings. A migratory fly is much influenced by attractive objects it may encounter, so that large numbers congregate in areas of defective sanitation. They will also follow vehicles along roads, especially farm carts or refuse-collecting vehicles.

The legs of the housefly are well developed and normal in appearance. The feet consist of a pair of claws by which the insect is able to grasp roughened surfaces and a pair of pads (the 'pulvilli') which are covered on their ventral surface with innumerable closely set hairs. These hairs secrete a sticky substance and it is by virtue of this that flies are able to walk on highly polished surfaces even when they are vertical or upside down. During the daytime, flies are active and spend much time visiting horizontal surfaces where they may encounter food; e.g. tables in houses or floors of animal houses, dairies, etc. At night, they retire to the upper parts of rooms to rest. When seeking places to rest, flies are especially attracted by narrow strips of material, dark lines or edges. They are especially prone to rest on vertically hanging cords (e.g. lamp fittings) and this habit is exploited in the common sticky fly-paper trap and in insecticide-impregnated cords (see pp. 132-133).

The abdomen contains the main digestive and reproductive organs. At the end of the abdomen of the female is a long thin ovipositor, formed of reduced segments which, when extended, equals the rest of the abdomen in length. When it is not in use, it is retracted into the posterior end of the abdomen, the segments being telescoped one within the other so that only the tip is visible from the outside.

Flies become sexually mature a day or two after emergence and thereafter mating can frequently be observed. The male seeks the female primarily by sight (since he will attempt to mate with other males or even small dark objects). In addition, a sexual odour emitted by the female stimulates his lust.<sup>(39)</sup> Normally, the male springs on to the back of a resting female, grasps her with his legs and strokes her head. The female may reject him by kicking backward; as a result, many too ardent males may be found with frayed wings. If the male is accepted, however, the female

introduces her ovipositor into his genital opening and union is effected. The act may last from a few moments to several minutes. The females begin to lay their eggs about four days after copulation.

Adult flies live for about a month in summer; under cooler conditions in winter, they have been kept alive for nearly three months.

#### (d) Bionomics of houseflies

##### (i) *Speed of development*

Like other insects, the housefly is profoundly influenced by temperature in its speed of development. There are a number of records of experiments at different temperatures which illustrate this fact, but unfortunately they are mostly unreliable because the temperature measured was that of the air above the breeding medium. Owing to putrefactive processes, the latter is almost always above air temperature, the amount depending on the bulk of the breeding matter. Experiments with flies reared in small quantities of breeding materials kept at different air temperatures gave the data set out in Table 8. (See also Fig. 8, p. 57.)

TABLE 8 *Observations on the speed of development of Musca domestica at different temperatures*

	Average durations of different stages (days)							Reference
	16°C 60°F	18°C 64°F	20°C 68°F	25°C 77°F	30°C 86°F	35°C 95°F	40°C 104°F	
Egg	1·7	1·4	1·1	0·66	0·42	0·33	—	(1)
Larva	11-26	10-14	8-10	6·5	4·5	3·5	5·0	(2) (3)
Pupa	18-23	12	9-10	6-7	4·5	4	4	(4) (6)
Total	32	23	19	11	8	6	9	(5) and (6)

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Generally the development occupies about 2 or 3 weeks in an English summer and a month or more in spring or autumn. Added to this must be a period of 3 days to a fortnight (according to temperature) for mating and maturation of the eggs. Taking 3 weeks as an approximate average for the complete life cycle during the summer, it is likely that there are about 4 to 6 generations during the breeding season.

With the advent of cooler weather in the autumn the life cycle increases in length and there is less and less outdoor activity of the adults. As a result, new breeding grounds get less and less attention from females seeking sites to lay their eggs. The numbers of flies fall off enormously in the winter and their method of passing the

winter has long been a point of controversy. It seems most likely that the great majority of flies die off in the autumn and that breeding diminishes. Probably the species continues by slow breeding in manure and kitchen refuse in stables, barns and similar sheltered spots. In the early summer there is certainly a vigorous recolonization of all available breeding sites.<sup>(33)</sup>

(ii) *Checks to population growth*

Various calculations have been made of the numbers of progeny deriving from a pair of houseflies in a single season, assuming that everyone survived and reproduced. Estimates vary from five billion to 190,000,000 billion. While this is more of an exercise in arithmetic than biology, it does serve to emphasize the rapid powers of multiplication of the fly and equally the importance of natural checks on population growth. The causes of mortality in nature are little understood. One important factor must be the food supply. Heavily infested horse manure often contains several hundred larvae to the pound. But when very large numbers are reached the larvae compete for food; many are stunted and become undersized adults while others die before reaching maturity. Certain nutritious foods can support very large numbers of maggots. A piece of liver weighing 5 gm (just under  $\frac{1}{6}$  oz) provides food for up to 70 maggots. Above this number they become stunted and some die; but half of them survive if 300 of them are crowded on this small piece.<sup>(54)</sup> It is, however, doubtful whether overcrowding of this type is the main check to population growth; if it were, one would expect to encounter many stunted flies in nature, but this is not the case. Perhaps the main restriction may be that few mature female flies in towns actually find suitable breeding material.

Houseflies suffer from depredations of a wide variety of natural enemies. In the egg and larval stages, they are preyed upon by various arthropods but especially by mites (*Macrocheles muscae domesticae*)<sup>(55)</sup> and certain ants. The larvae are also sensitive to pathogenic bacteria, including *Bacillus thuringiensis*. The pupal stage may be parasitized by various chalcid Hymenoptera. The adults are sensitive to a few staphylococcal bacteria, microsporidia (*Octosporea muscae domesticae*) and various fungi. The best known of the fungi is *Entomophthora (Empusa) muscae* which causes flies to die in exposed places, their bodies swollen with mycelia of the fungi; this is not uncommon in damp autumn weather.

Scarcely anything is known about the quantitative importance of these natural enemies and, in most cases, it is difficult to see how they could be used for biological control. Tentative experiments have been in mass rearing of *Macrocheles* mites<sup>(55)</sup> and rather more practical trials with *B. thuringiensis* (see p. 90). Another possibility is the fungus *Beauveria* sp., spores of which can be produced on a large scale and used against insects.

Some vertebrates (frogs and lizards) and some arthropods (spiders) prey upon the housefly, but it is very unlikely that they exert a profound effect on the fly population. A number of different mites and the pseudo-scorpion *Chermes nodosus* are occasionally found clinging to the bodies of flies but it is difficult to decide whether they are at all harmful or not; probably they merely use the fly as a convenient vector for dissemination.

### (e) Importance

#### *Transmission of disease*

Flies and blowflies which breed in media teeming with bacteria, including pathogens, might be expected to carry some of them from the larval stage to the emerging adult. However, on cessation of feeding, before pupation, there is a rapid decline in bacterial flora, and very few are retained in the adult. The main risk of disease transmission is dependent on the habits of the adults themselves.

There is no doubt that, in warmer climates, houseflies do take part in disease transmission. Control of flies has been shown to reduce enteric infections (Shigellosis) in southern U.S.A.<sup>(56)</sup> and in Italy.<sup>(32)</sup> In Egypt, the housefly and its relative *Musca sorbens* swarm over children's faces in the villages and transmit the germ of trachoma. On the other hand, the medical status of flies in northern Europe is more dubious. In the early years of the century, epidemics of infantile diarrhoea were suspected, on good evidence, of being fly-borne; but this is now much less common.<sup>(19)</sup> Not only does water-borne sanitation make human faeces much less accessible, but there is evidence that flies are not readily attracted by it, in cooler climates.<sup>(49)</sup> There are, of course, other sources of harmful bacteria; e.g. slaughter houses, animal faeces, soiled napkins or dressings in hospitals; and in general no one should willingly permit fly contamination of foods (especially that of young children).

#### *Annoyance from flies*

The presence of large numbers of flies is generally considered a disagreeable nuisance and outbreaks are usually the prelude to vigorous complaints to the health authorities.

On the whole, too, fly prevalence reflects the state of outdoor hygiene. In modern towns and cities, the disappearance of horse manure has left the fly only domestic refuse to breed in; and if this is properly disposed of, fly nuisances are rare. In rural districts, of course, the accumulation of manure in farms is inevitable; but again, efficient disposal should ameliorate the nuisance.

### (f) Control measures<sup>(62)</sup>

It is convenient to deal separately with fly control in urban and rural areas. In cities and towns fly nuisances are generally much less severe and, furthermore, the types of control measure acceptable in dwelling houses are more restricted than those available for barns, animal houses and dairies.

#### (i) Urban fly control

##### (α) Mechanical methods

Under this heading, we may mention fly papers, fly traps and fly 'swatters', which were formerly widely used but now are seldom seen. They are rather unsightly and inefficient.

Since flies breed out of doors, it would seem logical to prevent their invasion of houses by screens. In practice, however, this is difficult and expensive. Weather-proof wire gauze (10 mesh, 32 swg, is suitable, see p. 79) must be fitted outside all windows and this reduces light and ventilation and precludes the use of hinged

windows which open outward. Two pairs of swing doors separated by a trap porch are required for external communication, to prevent entry of flies. These difficulties largely restrict the employment of fly screens; though they may be worth consideration for special places such as restaurant kitchens, food factories (including jam, which attracts wasps) and portions of hospitals.

(β) *Sanitation*

Household garbage and, even more, the refuse from restaurants, contains a proportion of decomposing material, attractive to houseflies and blowflies, in which they can lay eggs and develop. Accordingly it is very desirable to keep the dustbin area clean and tidy and to use dustbins with properly fitting lids, which are kept in place. Further information on household refuse as a source of insect nuisances is given in Chapter 12 (pp. 336–340).

(γ) *Larvicides*

In the past, commercial 'tip dressings' of undisclosed composition were used; but they were seldom very effective. Sodium cyanide solution (3 gal of 1.5% per sq yd) was recommended, but too dangerous and troublesome for extensive use. The modern synthetic insecticides have never been entirely satisfactory; fly larvicides and the chlorinated compounds should be avoided because they are so prone to induce resistance. Perhaps the most satisfactory fly larvicide is a 0.2% diazinon emulsion, applied as a coarse spray at the rate of 6 to 12 gal per 1000 sq ft.

As a larvicide for use by the individual householder, paradichlorobenzene crystals, used at the rate of 2 oz per dustbin, should give control for a week or two.

(δ) *Adulticides*

Stomach poisons, used as poison baits, would not generally be suitable for dwellings and contact poisons as residual spray treatments would scarcely be worth while (especially in view of sporadic resistance). Use of aerosols, therefore, constitutes the principal measure against flies in urban areas. Three types may be employed.

(1) Insecticides dissolved in odourless kerosene, to be applied by hand atomizer. Suitable formulae are: 0.1% pyrethrins plus 1% synergist, such as piperonyl butoxide.

(2) Insecticide concentrate, to be dispensed by liquefied gas from a metal can. Suitable formulae: Pyrethrins, 0.4%; DDT, 3%; DDT solvent, 15–20%; non-volatile oil, 1–2%; Freon, 75–80%.

(3) Electrically heated aerosol generating cups, containing undiluted DDT and (or) *gamma* BHC, and emitting fine particles of insecticide (see p. 130). In case of possible health hazard, it is recommended that this type of generator should not give off more than 67 mgm/1000 cu ft of DDT or *gamma* BHC per day (see p. 148).

Types (1) and (2) are used as required. Recommendations about dosage are rather unrealistic, since most people use them by aiming jets at individual flies or groups, rather than producing a standard aerosol to fill the room.

Type (3) is operated continuously from the electrical supply. Its efficiency depends

on the amount of ventilation occurring. It will not, in any case, be effective against flies resistant to chlorinated insecticides.

(ε) *Chemosterilants*

Some tentative trials of chemosterilants for fly control have been made on isolated refuse tips in the U.S.A. Despite the incalculable toxic hazards of these compounds, it is possible that their use might be feasible on such sites. So far, however, no practical recommendations can be made (see pp. 110-112).

(ii) *Rural fly control*

(α) *Mechanical measures: screening*

On fly-infested farms, it may perhaps be worth considering the advisability of screening living quarters, or at least the kitchens.

It is worth noting that relatively coarse ( $\frac{3}{4}$  inch) netting or hanging bead screens, will exclude quite a proportion of houseflies; this is sometimes useful for protecting temporary structures such as dining tents or field latrines.

(β) *Sanitation*

On a farm, several sorts of dung may be available for fly breeding of which pig dung and horse dung are preferred by the fly. Some breeding will occur in the layer of straw and dung in stables and pigsties, but if these are cleaned out at reasonable intervals, the main breeding sites will be the dung heaps. Manure stacks beside stables and on allotments are also likely to be infested on a large scale. Whereas the flies from a badly kept manure heap on a farm will usually only annoy the occupants, the same nuisance in stables or market gardens in a partly built-up area will spread to adjacent households.

*Biothermic method*

Manure piled in a heap retains the heat generated in fermentation so that the great bulk of the dung is too hot for fly maggots which are accordingly restricted to a layer below the surface. If the pile is tightly compacted the heating is more uniform and persists for a longer time. A roughly cubical stack should be built with vertical sides patted tight with a shovel. New additions of horse dung (which is attractive to flies only while fresh) should, if possible, be buried in the hot centre of the pile under dung which has been exposed for some days.<sup>(40)</sup>

This method is more successful with horse manure than pig dung because the latter does not ferment so quickly nor reach so high a temperature.

*Maggot traps*

With some preliminary care and expense, fly breeding in manure heaps can be permanently reduced. The method is based on the tendency of fly maggots to leave fermenting manure and burrow in the soil to pupate. To prevent this, maggot-trapping manure stands can be built. The simplest form consists of a concrete base surrounded by a small moat of water. If the manure is kept tightly stacked as described above the maggots will migrate from it and will be trapped in the water

of the moat. A more complex type consists of wooden slats or a wire frame to hold the manure over a shallow trough filled with water. The manure is stacked tightly and occasionally watered in hot weather and the migrating larvae fall into the water as before.

The following measures have also been suggested but they are of doubtful practical value:

Manure attractive to flies (horse, pig) can be covered with cow dung which is hardly ever infested. Unfortunately cow dung is scarce in the summer fly season since the cows are out grazing in the fields.

Manure spread in thin layers to dry before stacking is scarcely attacked; but this is a laborious method and uncertain in a damp British summer.

Chickens allowed to scratch over a dung hill will eat numerous maggots; but it is doubtful if this biological control is highly effective.

### *Covering breeding material*

An effective fly control measure, which admittedly involves some trouble and expense, is to cover up a breeding site completely. This prevents the emergence of flies from maggots already present and denies other flies access for oviposition. Suitable breeding sites are manure stacks on farms, which may be covered with good sacking or, better, tarpaulin.<sup>(50)</sup> The method has also been found effective on a large mass of decomposing waste from a tomato cannery. This was covered by plastic sheeting measuring 100 × 144 feet. It cost £170 but abated a severe fly plague and was expected to last at least two years.<sup>(32a)</sup>

### *(γ) Larvicides*

Larvicidal treatments are handicapped by the danger of poisoning farmyard animals and by the possibility of impairing the manurial value of dung. This rules out some highly poisonous persistent chemicals, including arsenicals. On the other hand, fly maggots are very tolerant and are usually protected by the great bulk of the dung, so that large doses of insecticide are usually required to kill them.<sup>(44)</sup>

Among the older recommendations are the following treatments (per ton of manure): 1 gal creosote oil; 2–3 lb boric acid; 5 lb borax; 1½ lb paradichlorobenzene. More recently, 1 oz of thiourea per 25 cu ft manure has been found effective against flies resistant to chlorinated insecticides.<sup>(21)</sup>

### *Systemic treatments*

Various materials have been tested for suppression of fly breeding in dung, by incorporating them in the fodder or water of the animals to render the faeces insecticidal. Among the more promising are various organo-phosphorus compounds. Thus, dimethoate at 44 ppm in mash or 22 ppm in drinking water will suppress fly breeding in chicken dung without, apparently, harming the birds.<sup>(43)</sup>

Biological control, by adding spores of *Bacillus thuringiensis*, has shown some promise. Thus, mash containing 500 mgm/kgm of spores ( $25-75 \times 10^9$  per gm) prevented fly breeding in chicken dung in some trials.

*(δ) Adulticides**Residual spray treatments*

Residual spray treatments should be applied as described on page 126. Where resistance has not developed to chlorinated insecticides, the following may be used:

DDT	5%	concentration, at 200 mgm/sq ft insecticide			
or, methoxychlor	5%	„	„ 200	„	„
or, gamma BHC	0.5%	„	„ 20	„	„

Often, however, it may be necessary to employ organo-phosphorus insecticides, though these give less persistent residues (and in some areas have provoked resistance, too). Suitable compounds are malathion, dimethoate, fenclorophos, fenthion; all at 1%, to give 40 mgm/sq ft. Though suitable for animal houses, barns, etc., these compounds should not be applied extensively in living-rooms.

*Baits*

Poisoned baits may control flies in some cases, even when residual treatments fail. If applied properly they can be used in farm buildings without harming animals or contaminating milk. They may be prepared as (1) dry baits, for scattering, (2) liquid baits, (3) paint-on baits, (4) solid mixtures for 'bait-stations'. Some of these are commercially available; but, with a little trouble, they may be prepared from concentrates of malathion, diazinon, ronnel, dichlorvos, trichlorphon, naled, Dicapthon or dimetilan.

(1) Dry baits are prepared by mixing 1-2% insecticide with sugar (which should be discoloured by admixture of a little lamp-black to prevent its accidental consumption). Dry sugar bait is applied from a shaker-top can or glass jar on *dry* floors, window sills and other places where flies gather. Usually about 2 oz per 1000 sq ft, but if flies are numerous, heavier applications may be advisable.

(2) Liquid baits are made from water containing 10% sugar, molasses or syrup and 0.1 to 0.2% insecticide. They may be sprinkled on impermeable surfaces (clean concrete) at the rate of 1 gal per 1000 cu ft. Alternatively, they can be offered to flies in bait dispensers made from chicken-watering units modified by inserting a cellulose sponge in the trough, to prevent its becoming clogged with dead flies.<sup>(23)</sup>

A long-established liquid fly bait, still occasionally used, may be prepared by adding a teaspoonful of 40% formaldehyde to a cup of milk-and-water. This is offered in a saucer to the flies.

(3) Paint-on baits are prepared in a sticky form for application to vertical surfaces, such as posts, fences or the walls of animal pens. They are useful where dirty or muddy floors preclude the use of scattered dry or liquid baits. A 1-2% mixture of insecticide with molasses, corn-syrup or a thick sugar-water slurry, makes a satisfactory mixture to paint on surfaces where flies rest. The treatment should last a week or more.

(4) A convenient solid 'bait-station' may be prepared by fastening a 4-inch square of screen wire to a wooden handle about 6 inches long. The wire is coated with bait composed of 50% sugar, 46% sand, 2% insecticide, 2% gelatin (or better still bacto agar). The sugar and sand are thoroughly mixed. Boiling water is used to

liquefy the gelatin or agar, with stirring, and the liquid is then poured over the sugar-sand mixture and stirred thoroughly, adding the insecticide. A putty-like consistency should be achieved, adding more water if necessary, and the mixture is then spread over the screen wire squares and allowed to dry.

In use, the wooden handles of the bait-stations are pushed into the soil, round the edges of animal pens or into the manure of poultry houses, so that the baits are held in a vertical position just above the surface. They should be used 5-10 feet apart, where flies are numerous. They must, of course, be kept away from small children or animals.

#### *Cords and ribbons*<sup>(21)</sup>

In some regions cotton cords or strips treated with organo-phosphorus insecticide have given extended control of flies, when hung from the ceilings of animal houses. They are normally used at the rate of about 1 yard for each sq yd of floor area and are mainly effective in killing flies resting on them at night. Flat strips and ribbons are apparently rather more attractive than cords to flies seeking resting sites; and vertically hanging cords or strips are more attractive than those in shallow loops.

Cords and strips impregnated with diazinon and parathion are available commercially in some countries. Because of the high toxicity of these compounds, rubber gloves should be worn while hanging them up and all directions on the packages followed carefully.

### III · THE LESSER HOUSEFLY (*Fannia canicularis*)<sup>(29, 47)</sup>

#### (a) **Distinctive characters**

After the common housefly, the lesser housefly, *Fannia canicularis*, is the fly most frequently encountered indoors. Its abundance is sporadic, being most common in rural areas especially in the neighbourhood of poultry farms. *F. canicularis* is distinctly smaller than the common housefly, *M. domestica*, and the fourth vein on the wings curves gently away from the third instead of bending sharply towards it (Fig. 14*d*). Also, the wings in repose are held parallel (and partly folded over one another) instead of in a diverging position as in *M. domestica*. The flight of the lesser housefly is also characteristic. It spends much time circling beneath pendant lamps or similar fittings, making sudden erratic turns.

#### (b) **Life history**

*Fannia canicularis* can breed in various forms of moist decaying organic matter. It breeds very prolifically in large accumulations of chicken faeces and the ovipositing females will choose this in preference to other kinds of dung, possibly on account of its strong smell of ammonia.

The eggs are about 1 mm long, banana-shaped, with a pair of wing-like longitudinal ridges to assist flotation in a liquid medium. The larva is very characteristic in appearance (Fig. 16*d*). It is flattened and each segment bears a number of tail-like processes of uncertain function. There are three larval stages and the final one

reaches a length of 6–7 mm. The puparium, as usual, is formed of the last larval cuticle.

Most of the adult flies seen in houses are males, though females are quite common near breeding places. As already mentioned, the males spend much time circling aimlessly under pendent fittings, on which they occasionally rest, usually head downwards. At night, they rest on walls, ceilings and fittings in the upper part of rooms.

Experiments have shown that the biological temperature range of the lesser housefly is lower than that of the common housefly.<sup>(24, 34)</sup> Thus:

	Initial movements	Optimum	Heat paralysis
<i>M. domestica</i>	6.7°C	33–34°C	45°C
<i>F. canicularis</i>	4.2°C	24°C	40°C

There is also a suggestion that outbreaks of lesser houseflies occur earlier in the year. In the winter (Massachusetts, U.S.A.) *F. canicularis* has been found in all stages (except the egg) in poultry manure with minimum air and manure temperatures of 3° and 10°C respectively. In the laboratory at 27°C (80°F) the speed of development is: E, 1½–2; L, 8–10; P, 9–10; pre-oviposition, 4–5. Total (egg to egg), 22–27 days.

### (c) Importance

Intense breeding in poultry manure at large modern poultry farms has been the source of many severe nuisances due to this fly.

The habits of the lesser housefly rarely bring it in contact with human food and it is therefore not a vector of enteric diseases. It has, however, been discovered occasionally causing intestinal or urinary myiasis.

### (d) Control measures<sup>(13, 36, 47)</sup>

#### *Operational control*

Nearly all the serious outbreaks of *F. canicularis* in Britain are due to accumulations of manure in intensive poultry breeding farms. Many breeders allow the droppings to accumulate in pits, to save frequent disposal, and this provides an ideal breeding medium. The suitability of the chicken faeces can be reduced in two ways: by making it drier or wetter. Use of the deep litter system may somewhat improve the manure, but adds considerably to labour. Alternatively, in the 'lagoon' system, the dung is allowed to drop into a tank of water, the level of which is controlled.

#### *Adulticides*

The most satisfactory method of adult fly control has been the use of numerous hanging cords impregnated with contact insecticides. The fly strings are prepared from white absorbent cotton  $\frac{3}{32}$  inch in diameter used at the rate of 30 feet per 100 sq ft floor space in the chicken houses. They should be impregnated with fenchlorphos or diazinon, dipping the strings into 25% emulsion concentrate and allowing them to dry. Great care should be exercised in handling these concentrated

poisons. Rubber gloves should be worn during impregnation and also in handling the strings when dry (see Gradige, 1963, for full details).

### (e) The latrine fly

*Fannia scalaris* is known as the latrine fly from its habit of breeding in the site indicated. It is very rarely encountered indoors, but may sometimes be found in primitive privies, where the larvae are living in the faeces. It may be distinguished from *F. canicularis* as follows:

#### Larvae

The larvae resemble those of *F. canicularis* except that the tail-like processes are more distinctly branched (see Fig. 16d). Also the body segments of *F. canicularis* are crossed by median folds on the ventral side, whereas those of *F. scalaris* are smooth.

#### Pupae

*F. canicularis* has an anal opening hardened by a raised fold forming a raised 'V' with the point forward; while *F. scalaris* has an oval anus, with no V-shaped fold.

#### Adults

The tibiae of the middle pair of legs of *F. scalaris* each have a distinct tubercle, which is absent in *F. canicularis*.

## IV · 'SWARMING' HOUSEFLIES<sup>(53)</sup>

### (a) Distinctive characters

'Swarming' in the sense used here, has nothing to do with the highly specialized swarming of bees, nor of the dancing swarms of gnats and midges associated with mating. In the sense used here, swarming merely implies aggregation of large numbers of flies prior to hibernation. This may cause trouble in certain species which invade dwellings at this time. During the summer months, they live out-of-doors and are seldom noticed. Under natural conditions, most of them hibernate in dry sheltered places, as under loose bark or in hollow trees. In some rural or semi-rural areas, however, they may invade houses or other buildings and it appears that certain houses are chosen year after year. Most probably this is due to accidents of favourable location. Suitable places for hibernation are roof spaces and unheated and unoccupied rooms; also belfries and lofts above church meeting halls, etc. Sometimes they enter living-rooms, which is eventually fatal to them as a rule, because the high temperature keeps them active and depletes their food reserves. The nuisances due to these flies are especially prevalent in autumn, when they invade the houses, and in spring when they leave. In churches and meeting halls, which may be only heated at intervals, the hibernating swarms may be temporarily aroused to a semi-torpid activity and cause consternation by dropping down on to people in this state. Finally, another source of trouble is that flies may fall into roof cisterns in considerable numbers.

There are two distinct types of 'swarming' flies: (1) large (8–10 mm) muscid flies of the species *Pollenia rudis*, *Musca autumnalis*, *Dasyphora cyanella*, and *Muscina stabulans*; (2) the much smaller (3 mm) chloropid fly *Thaumatomyia notata*. Their swarming habits are somewhat different. The muscid species mentioned (which may occur separately, or together in various proportions) tend to aggregate on sunlit faces of buildings during warm days of autumn. As the temperature falls at night, they tend to crawl into crevices, sometimes under tiles and perhaps into spaces under the eaves or open windows. The following day they may emerge and sun themselves; but finally they remain permanently inside until the process is reversed in the following spring.

The small yellow swarming fly, *T. notata*, tends to hover in the lee of buildings, away from the prevailing wind. In cool weather they will invade rooms through open windows and crawl about on the ceiling. Usually, upper stories are most liable to invasion. They cause annoyance from dropping off the walls and flying up again; also the swarming areas may be heavily contaminated with excreta.

### *Recognition of species*

*Pollenia rudis* (Fig. 14f), the cluster fly, is not unlike a large housefly in general appearance, though it holds its wings folded over the back, in repose, not at a diverging angle, like the housefly. It is brown in colour and the thorax bears numerous golden hairs (which tend to become rubbed off, however). The abdomen has a dark median line and shifting irregular reflections. *P. rudis* is the most common of the swarming houseflies and it is especially objectionable from the sickly sweetish smell emitted by large clusters.

*Musca autumnalis* (formerly *M. corvina*), the raven fly, resembles the housefly but can be distinguished by the males (of which some are nearly always present in swarms). Both flies have a yellow abdomen with a central longitudinal stripe. In *M. autumnalis* the stripe is well defined and the yellow area very bright; whereas the stripe in *M. domestica* is less defined and the yellow more dusty pale. In *M. autumnalis* males the eyes practically touch, whereas those of *M. domestica* are separated by a strip about one-sixth of the head width.

*Muscina stabulans* (Fig. 14g) also resembles a rather large housefly, but can be distinguished by the fourth longitudinal vein on the wing, which is gently curved forward towards the third vein, not sharply angled, as in *Musca*.

*Dasyphora cyanella* is very similar in appearance to the common greenbottle flies of the genus *Lucilia*. It can be readily distinguished, however, by the thorax, which has two longitudinal dark marks on the upper surface.

*Thaumatomyia notata* (Fig. 15c) is a small yellow fly with black markings.

### (b) Life histories

#### *Pollenia rudis*

This fly has an interesting and unusual life cycle. The females lay eggs under dead leaves etc. on the soil. The larvae hatch in about a week and seek certain species of earthworm, pierce them and live parasitically inside. In the original observations of the life cycle, in France, the worm *Allolobophora chlorotica* was involved.<sup>(22)</sup> In

North America the worm *Eisenia rosea* has been attacked. There is no information as to the host worm in Britain, though both species occur here. During its growth the larva (which resembles an ordinary maggot) extrudes its hinder end through the skin of the worm, usually near the mouth; thus the larva's spiracles gain access to the air. Eventually, when the host is largely consumed, the larva leaves it and apparently may attack other worms as predators, from the outside. Eventually, when fully grown, the larvae pupate in the soil.

Near Paris, apparently, there are two generations a year; but around Washington D.C. the warm summer accelerates development to the space of 4 to 6 weeks and there are several summer generations.

### *Musca autumnalis*

The females lay eggs on tiny stalks on patches of dung in the fields. The larvae feed on the dung and eventually pupate in the soil. The adults associate with cattle and horses in the fields in the summer months, feeding on secretions and sweat. Though unable to pierce the skin, these flies will readily drink blood from small scratches or the punctures of true bloodsucking flies. Introduced into North America about 1950, it has spread widely and become a troublesome pest of cattle, being known there as the face fly.

As a swarming housefly, *M. autumnalis* is troublesome in spring, when it leaves houses, as well as in the autumn, when it enters.

### *Dasyphora cyanella*

This species also breeds in cow dung scattered in the fields. The females lay batches of 25–30 eggs, just below the surface of the manure. In south-west Scotland, the eggs take 1–3 days; larvae about 4 weeks; pupation 3–4 weeks; total about 8 weeks. Adults may be seen in the fields from May to November, after which they hibernate.

### *Muscina stabulans* (Fig. 14g)

The females lay eggs (up to 160) on various forms of decaying animal and vegetable matter. The young larvae are scavengers, but the older ones attack and feed on other maggots. Development takes 31 days at 16°C (60°F); 18 days at 21°C (70°F) and 14 days at 28°C (82°F).

### *Thaumatomyia notata*<sup>(37)</sup>

The eggs are laid in the soil around the roots of grasses and the young larvae attack and feed on the root aphid, *Pemphigus bursarius*. There are two generations per year, the second of which normally spends the winter as pupae in the soil, which emerge in the spring.

In a warm autumn, however, adults emerge from many of these pupae, and these constitute the swarms of tiny flies which seek shelter in houses when the cool weather arrives. Most of these adults, however, do not survive hibernation.

## (c) Control of swarming houseflies

No substance is known which will repel these flies for several weeks and prevent them entering a building. On the other hand, the insecticides lethal to the

ordinary housefly will effectively kill the hibernating species. The problem is one of application.

*Lofts, barns, roof spaces, belfries, etc.*

In these situations, where there are no furnishings or decorations to spoil, insecticidal smoke generators (see p. 130) can be used satisfactorily. Those containing DDT, gamma BHC or a mixture of the two are generally satisfactory. Insecticidal smokes leave very little residual deposit, except on horizontal surfaces; therefore it is advisable to employ them when the flies have moved into their winter quarters. Application during strong winds should be avoided, as many roofs are surprisingly porous and the smoke may be blown away too rapidly. Smoke penetrating between tiles and through similar crevices may be beneficial in driving out flies lodged in these places. Smoke generators should be ignited with sensible precautions against fire; generally speaking this presents no difficulty. In addition, open cisterns in roof spaces should be covered during their operation.

*Large rooms, halls, etc.*

A space spray of 1.3% pyrethrins (or its synergized equivalent) in light oil should be dispensed from a mechanical aerosol generator at the rate of 1 pint per 40,000 cu ft.

*Domestic rooms*

A household aerosol based on pyrethrins is convenient and effective, whether applied from a liquefied gas aerosol dispenser or a hand atomizer. It is advisable to warm up cold rooms before using the aerosol, to increase activity of the flies.

A useful method which obviates the collection of dead flies is to collect them directly with a vacuum cleaner and then to draw into the bag a little DDT or BHC dust and leave for a few hours before emptying.

## V · FLIES FROM SEWAGE WORKS<sup>(52)</sup>

Certain kinds of small flies breed in large numbers in the filter beds at sewage works (see Chapter 12). Normally they are harmless and even beneficial to the proper operation of sewage filtration. Occasionally in the summer months, however, conditions favour enormous proliferation of these flies and large swarms are produced which become a nuisance in areas adjacent to the sewage works. The species most liable to cause trouble are *Psychoda alternata* and *P. severini* (tiny black 'moth flies') (Fig. 15b) and *Anisopus fenestralis* (a rather large 'window gnat') (Fig. 15a). The presence of large numbers of these flies is objectionable from their liability to get into the eyes, nose or mouth. Apart from being a nuisance out of doors, both types (but more especially *Anisopus*) may invade houses in considerable numbers. A still more unpleasant feature of *Anisopus* is the readiness with which it lays masses of eggs on any moist object. Damp foods may often have to be discarded for this reason.

It appears that insecticides and methods used to control adults of the ordinary housefly will destroy these unpleasant little flies. But their enormous numbers in



*a*



*b*



*c*



*d*



*f*



*g*



*e*



*h*

FIG. 15. Some small flies found in houses. (*a*) *Anisopus fenestralis* (the window gnat); (*b*) *Psychoda alternata* (a moth fly); (*c*) *Thaumatomya notata*; (*d*) *Piophilidae casei* (the cheese skipper); (*e*) *Drosophila funebris* (a fruit-fly); (*f*) back of thorax of same; (*g*) back of thorax of *Drosophila repleta*; (*h*) *Megaelia scalaris* (a phorid). (*e*) & (*h*) after Smart, *Insects of Med. Importance* (B.M. 1943), the remainder original. (*a*)  $\times 4$ ; (*b*)  $\times 10$ ; (*c*)  $\times 12$ ; (*d*)  $\times 7$ ; (*e*)  $\times 8$ ; (*f*)  $\times 14$ .

the limited nuisance areas reduce the value of such measures to doubtful palliatives. More radical methods at the breeding sites are discussed in Chapter 12.

## VI · BLOWFLIES (*Calliphoridae*)

### (a) Distinctive characters

The morphological character distinguishing the family *Calliphoridae* (e.g. from the *Muscidae*) is the presence of a row of bristles on the hypopleuron below the hind thoracic spiracle. While this systematic criterion is somewhat subtle, many blowflies can be easily recognized by their general appearance. The well-known bluebottles, greenbottles and the grey flesh fly, being representatives of the family in Britain.

#### *Identification of important genera and species*

##### *Calliphora*

*Calliphora* spp. are the common bluebottles, which are dull, metallic blue colour and rather bristly, about 11 mm long with a 25-mm wing span. *C. erythrocephala* (Fig. 14a) is the common species; but in early literature it was often confused with *C. vomitoria*. The former has a face with reddish jowls bearing black hairs; whereas the latter has black or dark grey jowls with reddish hairs.

##### *Lucilia*

*Lucilia* spp. are the common greenbottles. They are rather variable in colour, from metallic bluish green to copper colour. They are less bristly than *Calliphora*, about 10 mm long with an 18-mm wing span. *L. sericata* (Fig. 14e) is most common and the most important species (being responsible for most attacks on sheep). *L. caesar* is also prevalent. Distinction of the species depends on numbers of 'acrostical' bristles on the back of the thorax.

##### *Phormia*

The adults of *P. terrae-novae* are rather like undersized bluebottles, with a deeper almost purple blue colour and rather more bristles. Length 8–11 mm.

##### *Sarcophaga*

The flesh fly *S. carnaria* (Fig. 14c) is greyish, with a striped thorax and checkered abdomen. Length about 13 mm, wing span about 22 mm. It is rather less common and important than other genera but sometimes frequents dustbins during summer.

### (b) Life history<sup>(5, 7, 10, 14)</sup>

#### (i) Oviposition

The adult blowfly begins oviposition about 3 to 7 days after emergence. At 24°C, the comparative pre-oviposition periods for various genera are: *Calliphora*, 4–5 days; *Lucilia*, 4–5 days; *Phormia*, 6–7 days.

The breeding requirements of blowflies are best filled by decaying matter of animal origin. Cadavers are the preferred breeding site of most blowflies, but some are also able to develop in suppurating wounds or sores on living animals. Others

will breed adequately in animal faeces or even, occasionally, on decaying vegetable matter.

Blowflies have highly developed olfactory organs, which are very efficient in enabling them to locate breeding sites. During the summer, the exposure of meat or carcasses of animals soon attracts female blowflies, seeking to lay eggs. Large egg masses are laid, sometimes comprising as many as 200; and if many blowflies are present, excessive numbers accumulate and many of the larvae cannot complete development. Nevertheless, the body of a small animal weighing only 16 oz will provide sufficient nutriment to breed up to 4000 blowflies. Generally speaking, blowflies are reluctant to enter buildings unless attracted by the presence of flesh; in this case they often enter by a sunlit window or door and leave soon after laying their eggs. Sometimes, however, *Calliphora* will oviposit at night, though *Lucilia* apparently does not.

Certain substances are particularly attractive to blowflies. Waste entrails at slaughter houses are especially attractive and can become heavily infested with eggs soon after removal from the body. Blowflies also show preference for cut surfaces of carcasses and also the kidney region, which *Lucilia* in particular is prone to choose for egg-laying. Liver, on the other hand, is not attractive for the first three hours after removal from the carcass, though it will readily become infested thereafter.

#### (ii) Egg

The egg period varies according to the age of the egg when laid and the temperature and humidity; most commonly, eggs hatch in 12–16 hours. If suitable material on which to oviposit is not available, the gravid females retain the eggs as long as possible. In such circumstances, eggs hatch in a very short time; both *Calliphora erythrocephala* and *C. vomitoria* have been observed to deposit living, newly hatched larvae. This is the normal practice in *Sarcophaga*.

#### (iii) Larva

For the first few hours after hatching from the egg, the maggots are more or less indifferent to light. Thereafter they tend to avoid it and burrow into crevices in the meat. The larvae feed on the liquefied tissues, dissolved partly by proteolytic bacteria and partly by enzymes secreted by themselves. They grow rapidly and moult three times. Shortly before pupation, most blowflies cease feeding and tend to migrate away from the feeding medium. Migration usually occurs at night. It has been suggested that this dispersion helps to avoid the concentrated attack of parasites and predators. The larvae travel over the ground until they find suitable loose soil in which to burrow and pupate. Usually this is within 20 feet; but if the ground is hard or waterlogged, they may travel 80–100 feet.

#### (iv) Pupa

Pupation usually occurs in the top 2 inches of soil (sometimes a little deeper). If soft earth is not available they will pupate in cracks in walls, under sacks or other objects. *Phormia* larvae, unlike those of other blowflies, often pupate on the surface of the breeding medium, unless it is very wet or exposed to bright light.

(v) *Adult*

Blowflies are strong fliers and range considerable distances from the breeding sites. In country districts, populations of *C. erythrocephala* up to 1000 per acre have been estimated in peak periods. In urban districts, aggregations occur in areas attractive to the blowflies, such as refuse and garbage, especially that from butchers, fish shops and, above all, slaughter houses.

Blowflies are most active in warm sunny weather. In cool cloudy weather all of them (but especially *Lucilia*) tend to disappear to resting sites. These are usually on vegetation adjacent to the attractive sites (*Calliphora*, *Lucilia*) though *Phormia* tends to disperse more widely. In warm weather, *Phormia* often rests on sunlit walls.

The various blowflies vary in relative prevalence at different times of the year. Normally, all of them hibernate, in the soil, as fully grown larvae. Adults of *Calliphora* begin to emerge first, usually in April, but sometimes as early as late January. *Phormia* adults are observed next and finally *Lucilia* adults begin to emerge in May. In midsummer *Lucilia* become considerably more abundant than flies of the other genera; but, in late autumn, the *Lucilia* decline first and *Calliphora* adults are last seen.

*Speed of development.* At 24°C (75°F) single cultures on liver. The two figures for L are feeding period + post-feeding period. *C. erythrocephala*: E, 0.15–0.3; L, 4–5 + 2.5–7.5; P, 8–13. *L. sericata*: E, 0.5; L, 4–5 + 4.5–9; P, 7–9. *P. terraenovae*: E, 1; L, 6 + 1; P, 5–7. Total development in competition in slaughter-house refuse. *Calliphora*, 19–22; *Lucilia*, 13–19; *Phormia*, 9–16. *Sarcophaga* (data from another source) at 21°C (70°F), 25; at 25°C (77°F), 17; at 29°C (84°F), 13.

(c) **Importance**

In nature, blowflies perform a useful function in disposing of carrion; nevertheless, their habits render them annoying or troublesome to man in several ways.

(i) *Transmission of disease germs*

Blowflies are very commonly heavily contaminated with micro-organisms. One investigator, who recorded an average of 27,000 organisms on houseflies, found  $3\frac{1}{2}$  times as many on bluebottles and 14 times as many on flesh flies. In many cases pathogenic organisms are involved. Thus, blowflies having access to carrion and offal in slaughter houses have been shown to be contaminated with bacteria *Salmonella* and *Clostridium*.<sup>(16, 17, 18)</sup> Their chances of transferring these to human food about to be consumed, however, is not very high. There is also evidence that *Lucilia* sp. may carry poliomyelitis virus (especially during epidemics) and it has been suggested that this presents an opportunity for transmission of the disease, if these blowflies visit small wounds.<sup>(35)</sup>

(ii) *Losses due to 'fly-blown' meat, etc.*

Meat or fish intended for human consumption must be protected from oviposition of blowflies, otherwise it will become 'fly-blown'. At slaughter houses, bacon-curing

or fish-curing establishments this may be a source of economic loss due to condemning of 'blown' meat or fish. In butchers' shops or fishmongers' there is an additional risk of unfavourable reactions of potential customers. In the domestic larder there is not only the wastage of spoiled food but, where cooked meat is concerned, the possibility of swallowing live eggs or maggots; this will be considered in Section VII, under 'Intestinal myiasis'.

#### (d) **Control**<sup>(15)</sup>

The major breeding sites of blowflies, at least in urban areas, are waste products; either domestic refuse or the offal and other waste of slaughter houses. Accordingly the problems of control are considered in Chapter 12. Other aspects considered here are the protection of food and avoidance of fly-attracting odours.

##### *Fishmongers' shops, etc.*<sup>(6)</sup>

Protection of the fish may be ensured by plastic containers, refrigerated showcases, etc., and this will also tend to reduce fly-attracting odours.

General hygiene involves daily washing of the floors, taking care that no fish waste is left in corners or trapped in internal drain covers. This washing is facilitated by hard smooth floor surfaces. Offal buckets should be removed at least once a day.

Insecticides should not be used when food is exposed (even resident deposits on walls are inadvisable since they may result in partly paralysed flies falling on to the goods offered for sale). After removal of foods, any flies present can be destroyed by use of an aerosol (see p. 128). Afterwards, all surfaces on which food is placed should be scrubbed and hosed down.

Hygiene is also essential outside the premises. The floors of yards and outhouses should be of concrete sloping towards drains and should be hosed down at least once a day. Drains, of course, must be kept clear and functioning.

Fish waste and offal should be kept in bins with tightly fitting lids, preferably kept in an outhouse. The contents should be removed daily and certainly at least every two days. The outside of the bins (and both sides of the lids) should be sprayed with 5% DDT suspension, weekly in the main fly season. Walls and fences should be sprayed with the same insecticide at fortnightly intervals.

Fish boxes should be scrubbed out with detergent when empty, rinsed with hypochlorite solution and allowed to dry. (Wooden boxes need 5 pints commercial hypochlorite in 8 gal water; aluminium boxes only  $\frac{1}{2}$  pint in 8 gal.)

##### *Bacon-curing establishments*<sup>(6a)</sup>

At nearly all stages of curing, bacon is in danger from the blowflies *Calliphora* and *Lucilia* as well as (to a lesser extent) from the fly *Piophilidae casei*. Some protection is afforded during immersion in brine and, during transportation, from hessian wrappings. The main period of risk is just before storing, when the sides of bacon are hung unprotected in the stores.

Since it is the practice to dust bacon sides with pea-flour at this point, the addition of a non-poisonous insecticide to the pea-flour was tried and found effective. The effective mixture was pyrethrins and piperonyl butoxide at the rate of 8 and 80 mgm

per sq ft respectively. The required amounts, incorporated in the pea-flour, did not affect the flavour of the bacon.

### *Domestic premises*

Indoors the only measure necessary against blowflies is the use of safes (or refrigerators) to protect meat, fish or game from them. In the back yard, careful attention to dustbin hygiene will prevent the attraction of blowflies to the house.

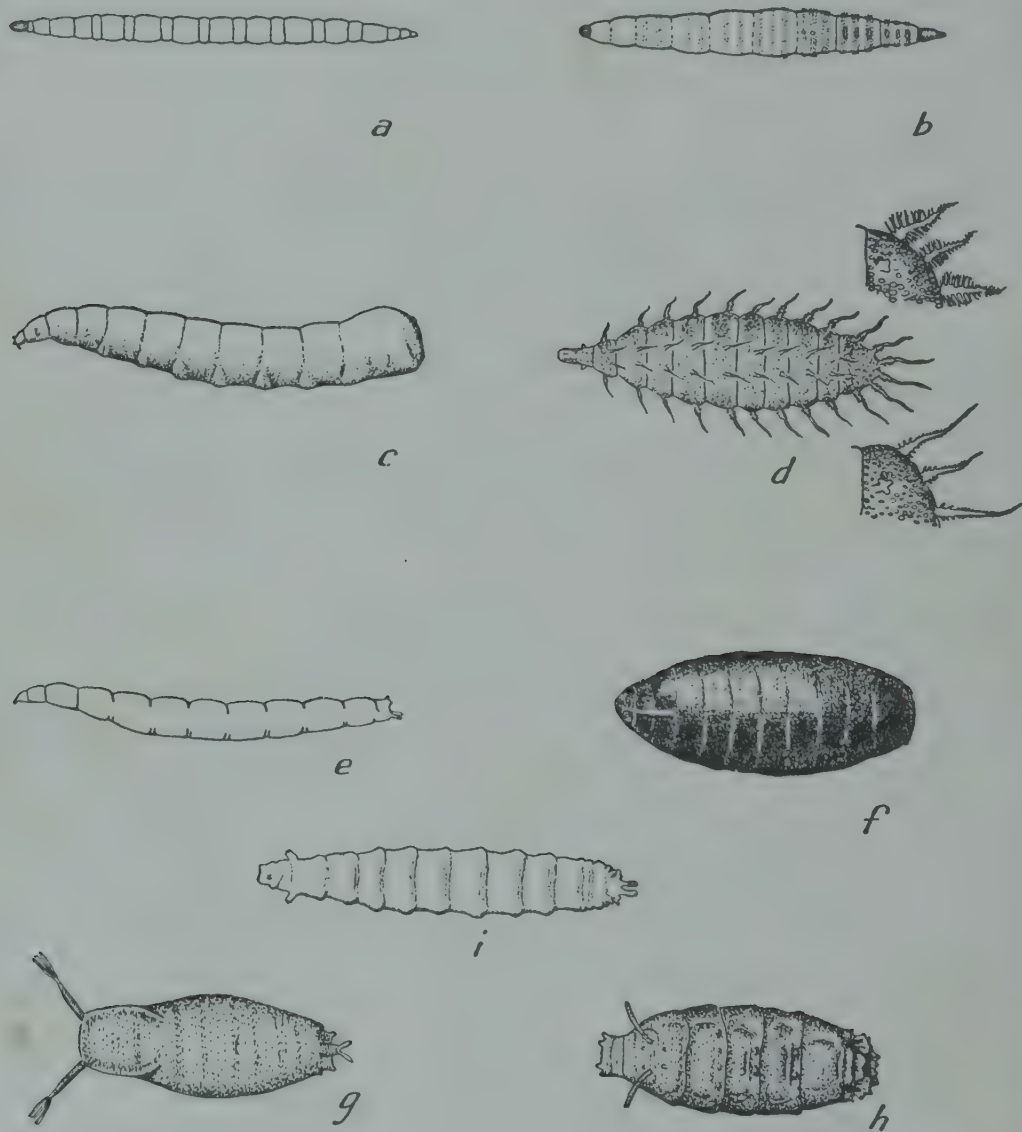


FIG. 16. Some larvae and puparia of flies. Larvae: (a) *Anisopus*; (b) *Psychoda*; (c) *Musca domestica*; (d) *Fannia canicularis* with enlarged drawing of part of the posterior end of same (below) and of *F. scalaris* (above); (e) *Piophilidae casei*; (i) *Drosophila melanogaster*. Puparia: (f) *Musca domestica*; (g) *Drosophila repleta*; (h) *Megaselia scalaris* (a phorid); (g) & (h) original, remainder after Smart, l.c. (a)  $\times 3$ ; (b)  $\times 3\frac{1}{2}$ ; (c)  $\times 4$ ; (d)  $\times 7$ ; (e)  $\times 5$ ; (f)  $\times 6$ ; (g)  $\times 7$ ; (h)  $\times 6$ ; (i)  $\times 9$ .

## VII · MYIASIS

By this term is meant the invasion of living tissues of man or animals by fly maggots. In most cases the infestation is accidental or facultative, but there are certain groups of flies which always pass their larval stage parasitically in the body of an animal; these 'bot flies' constitute a veterinary problem and will not be considered further.

Various parts of the body may be concerned in myiasis, especially the intestinal tract, various natural cavities lined with mucous membrane and open wounds or sores. The flies liable to cause facultative myiasis are distributed among a considerable range of families with members having the common habit of breeding in decaying vegetable or animal matter and adults which shelter in houses. (The common housefly, however, is rarely implicated, it does not breed in materials likely to be eaten or drunk.) Since the flies concerned are obnoxious in the larval form it is desirable to be able to identify them in this stage. A key to these larvae is given in the Appendix (p. 443).<sup>(46)</sup>

(a) **Intestinal myiasis**<sup>(3, 11, 20, 26)</sup>

There is a considerable number of records of fly maggots being vomited from the stomach or being evacuated from the bowels. All of the offending maggots normally feed on decaying organic matter and the usual mode of entry is by swallowing eggs or young larvae on uncooked food such as cold meat, cheese, fruit, etc. Very often, of course, the insects are destroyed and digested, but sometimes they survive and give rise to symptoms such as stomach pains, nausea, vomiting and diarrhoea with discharge of blood.

Certain accounts describe astonishingly prolonged disturbances attributed to intestinal myiasis, in which patients have been said to pass maggots with the faeces over a period of months or even years. In view of these prolonged attacks, it has been suggested that the maggots must be capable of developing and breeding in the intestines, either by a paedogenesis (non-sexual reproduction by larvae) or by completing the life cycle and by the adult flies mating inside the intestines. Such speculations have given rise to considerable doubts, especially in view of the fact that the flies concerned are very liable to oviposit in faeces so that their presence in stools might be explained by contamination of the receptacle. Sceptical writers have even doubted the possibility of larvae ever passing through the intestines alive, since in experiments with various animals, fly larvae have almost always been killed after a short period in the gut. However, it is difficult to refute the observations of certain competent observers of these cases and the position may be summarized as follows.

Eggs and larvae of certain flies are sometimes swallowed with food and may persist alive for some time, giving rise to acute gastric or enteric disorders. Cases have been reported where live larvae have been evacuated or vomited at intervals over long periods. Lack of oxygen and other conditions render it difficult to understand how larvae can exist for very long periods in the bowel: therefore such instances should be carefully investigated to determine whether the stools or vomit could have been contaminated after evacuation. Alternatively it may be possible that some habit

of the patient renders repeated infestation likely. The species of fly concerned may give a clue to this.

A totally different explanation of myiasis of the lower bowel is infestation *per anum*. People using primitive privies or latrines, especially if constipated or with sores in the peri-anal region, are liable to attract flies when at stool. The flies might have opportunity to oviposit and presumably this might give rise to myiasis if the larvae entered the anus.

### (b) Urinary myiasis

There have been reports of maggot infestations of the bladder and urinary meatus, though this is less common than intestinal myiasis. The flies concerned are mainly *Fannia* spp. and *Musca domestica*. In investigating these conditions, the same caution is needed to exclude contamination of urine. (The author has once or twice been brought clothes moth larvae alleged to be passed in urine but which probably fell from the patient's bedding into the receptacle.)

### (c) Myiasis of wounds

In this country, maggot infestation of wounds and sores in man is happily very rare. A number of British soldiers have, however, experienced it abroad in transit to hospital after being wounded. Actually the presence of maggots in wounds is not necessarily serious, provided the infestation is removed at the right time. They tend to feed on necrotic tissues and may expedite healing. Sterile maggots have even been used in surgery for treating tubercular abscesses and complex fractures. However, the natural unregulated infestation is not to be recommended and is certainly very distressing for the sufferer.

In peace time the chief sufferers from wound myiasis in Britain are animals, especially sheep. The flies mainly responsible are *Lucilia*, *Calliphora* and *Sarcophaga*. Infestations may not depend on actual wounds, since *Lucilia* females are attracted by faeces in soiled fleece in the crutch of the sheep. Maggots develop first in the soiled fleece and later break the skin and make a festering wound which attracts further blowflies. The eventual result, if the infestation is not checked, is the death of the sheep.

## VIII · THE FRUIT FLIES<sup>(12)</sup>

The small flies of the family Drosophilidae naturally breed in various fermenting materials, especially decaying fruit. Infestations sometimes occur in vinegar or pickle works, breweries or fruit canning factories. Some species frequent dwelling houses and show a remarkable propensity for finding and hovering about ripe fruit, alcoholic beverages and other substances giving off odours resembling their natural breeding materials.

Two important species are *Drosophila repleta* and *D. funebris*. Considerably more biological data exists for *D. melanogaster*, which is less common in Britain but has been widely used for genetical experiments in many countries. It seems likely, however, that the life cycles of the various species would not be greatly different. The following data is relevant to *D. melanogaster*.<sup>(30)</sup>

The females lay from about 400 to 900 eggs at the rate of some 15 to 25 per day. The larvae hatch and burrow into the breeding material. There are three larval stages separated by moults and finally the larvae crawl out of the food to pupate, preferably in loose soil. The total development takes about 30 days at 15°C (59°F); 14 days at 20°C (68°F); 10 days at 25°C (77°F); and 7½ days at 30°C (86°F). (*D. repleta* is apparently very similar.) The average adult life ranges from 13 days at 30°C (86°F) to 120 days at 10°C (50°F).

*Drosophila repleta* (Figs. 15g and 16g)

This species is believed to be tropical in origin but has been steadily extending its range in recent decades. The first record in Britain is quite recent (1942)<sup>(4)</sup> but it is already quite common in London and other localities. It breeds in rotting vegetables and is quite often troublesome in canteens, restaurants, hospital kitchens and so forth. Owing to the predilection of the adult for feeding on faecal matter combined with a habit of alighting on white articles in human houses (plates, tablecloths!) this fly may involve a certain danger of disease transmission,<sup>(48)</sup> especially in such places as hospitals. Owing to its very small size the insect is less noticeable than the common housefly.

The simplest method of control would seem to be to trace the breeding site and remove and destroy the decomposing vegetable matter concerned.

*Drosophila funebris* (Fig. 15e, f)

This fly has the habit, like certain others (Phoridae), of breeding in sour milk curds. Milk bottles which are left with residues in the bottom provide suitable breeding sites and the maggots often develop to the pupal stage before the bottles are returned to the dairy. The puparia (which look somewhat like brown seeds) are tightly cemented to the wall of the bottle and cannot easily be dislodged. It quite often happens that these puparia are not cleaned out by the bottle-washing process and are overlooked when the bottles are refilled with fresh milk. The result is often a complaint to the local health department which sometimes results in legal proceedings against the milk vendors.

## IX · PHORIDAE (Figs. 15h and 16h)

The adults of the small flies in this family seldom come to notice, but, as mentioned above, the puparia are quite often discovered in improperly cleaned milk bottles. Phorid larvae breed in different kinds of decaying organic matter and some have frequently been reported as breeding in dead snails. There are several accounts of intestinal myiasis due to phorid larvae.

One of the phorids, *Megaselia halterata*, is a common pest of cultivated mushrooms. While this is mainly a horticultural problem, it is worth noting that the adults are sometimes produced in such vast numbers as to constitute a nuisance to people living near to the mushroom growers.

## X · THE 'CHEESE SKIPPER' (*Piophilæ casei*) (Fig. 15*d* and 16*e*)

The larvae of the fly *Piophilæ casei* were formerly not uncommon breeders in the softer and riper varieties of cheese, in which some people considered them to be proof of excellent quality rather than a revolting infestation. An occasional result of this rather medieval outlook was intestinal myiasis accompanied by acute gastric symptoms.

In addition to ripe cheese, the flies will infest other proteinaceous foods such as ham or smoked meat or fish. Sometimes they cause large infestations in meat curing factories.

### (a) Life history<sup>(25, 38)</sup>

The females lay eggs in various sized batches in crevices in or near a suitable food supply. They may be laid on wrappers or on muslin covers. The larvae on hatching find their way to the food and burrow into it. Unlike certain beetle larvae which feed on dried meats and similar substances (*Necrobia*; *Dermestes*) these larvae are not confined to the superficial layers but may burrow deep into the food. In infested hams, for example, they may penetrate deeply especially alongside the bone. There are three larval stages and the maggots reach a length of about 8 mm.

The larvae are known as 'cheese skippers' from their curious habit of projecting themselves a short distance through the air if they are disturbed. This is achieved by bending the body double and gripping the edge of the last abdominal segment with the mouth-hooks. The muscles are then tautened and, when the grip of the mouth-hooks is released, the body extends violently and projects the maggot as much as 6 to 8 inches in the air or about 10 inches horizontally.

The fully grown larvae leave the food and pupate in dark corners or crevices nearby. A puparium like that of the housefly is formed of the last larval skin. The adults live for about 5 days at 24°C (75°F) and about 3 weeks at 15°C (59°F) on the average, the maximum observed being 39 days. The females can begin oviposition about 10 hours after mating. They lay about 140 eggs (maximum 500) over a period of 2 to 4 days.

### *Speed of development*

At 27–32°C (80–90°F) the incubation of the egg takes about a day and the larval period 5 days. Pupation occupies 8 days at 25°C (77°F) and 6 days at 30°C (86°F). Thus the total development can occur within a fortnight under very hot summer conditions, but about 3 weeks is more likely in the British summer.

### (b) Resistance to adverse conditions<sup>(46)</sup>

The larvae are remarkable resistant to certain adverse conditions. Thus, they can survive several hours in an air temperature of 51°C (124°F), though immersion for 2 minutes in water at 54.5°C (130°F) is lethal. Towards extreme cold, the half-grown larvae are more resistant than other stages; some have survived –15°C (5°F) for 64 hours.

Fully grown larvae will remain alive for 6 months at 9–10°C (48–50°F) and the adults may live for up to a month, without food, under these conditions.

(c) **Control**

The larvae are very difficult to destroy, partly because of their natural resistance and partly because they are normally protected by the foodstuff in which they are buried.

Prevention is better than cure and should take the form of careful cleansing of large meat store rooms (fumigation may be necessary) followed by protective measures. Careful screening (30 mesh wire screens) of meat store rooms, waxing of cheeses and hanging of hams in thick cloth bags are suitable measures. To prevent domestic infestations it is usually sufficient to keep foods liable to infestation in an ice chest or refrigerator.

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## 9 · *Bloodsucking flies*

### I · INTRODUCTION

#### **Feeding habits of biting flies<sup>(6)</sup>**

Bloodsucking is widespread in the many families of Diptera and it is possible that this was the original habit of ancestors of the group. Some forms seize and suck the blood of other insects; but many prey on the blood of vertebrates (especially mammals and birds) and we are here concerned with these. In the more primitive sub-orders, Nematocera and Brachycera, only the females take blood, while both sexes take sugar, usually from the nectar of flowers. The sugar is necessary for activity of daily life, while the protein of blood is utilized for egg production.

The mouthparts used for piercing and sucking in these groups comprise a bundle of piercing stylets carried on a flexible labium (Fig. 22, p. 214). The stylets are formed from highly modified mandibles and maxillae, together with a blade-like labrum and a narrow hypopharynx carrying the salivary duct. These piercing elements are more or less vestigial in the males.

In the highest sub-order of Cyclorrhapha, the bloodsucking habit of the females was abandoned, and the piercing mouthparts disappeared. Feeding was done by licking with the sponge-like labella at the tip of the labium. There was still a tendency for females to need protein for egg development, but this may be obtained from various sources (liquid excreta, milk, pollen).

Finally, a secondary development of bloodsucking has occurred in isolated groups of Cyclorrhapha. This may have developed from the habit of some flies with licking mouthparts which take blood from small wounds. Later, teeth in the labium assisted a rasping action and finally a horny piercing labellum was evolved in some genera. It will be seen that the redeveloped biting mechanism is quite different from the primitive one (necessarily so, since no piercing mandibles and maxillae are present). Also, both sexes take blood though they also take separate meals of nectar.

#### **Groups of biting Diptera**

The groups to be considered in this chapter are as follows:

##### *Nematocera*

Culicidae (mosquitoes)

Chironomidae (non-biting midges, liable to be confused with mosquitoes)

Ceratopogonidae (biting midges)

Simuliidae (black flies)

##### *Brachycera*

Tabanidae (horseflies)

*Cyclorrhapha*

(Biting) Muscidae (stable fly, etc.)

Hippoboscidae (forest fly; sheep ked)

## II · MOSQUITOES (Culicidae)

### (a) Historical note

The goodman of Paris (1392) referred to earlier (p. 153) had something to say on mosquitoes, thus:

I have seen, in divers chambers, that when one has gone to bed, they were full of mosquitoes, which at the smoke of the breath came to sit on the faces of those that slept and stung them so hard that they were fain to get up and light a fire of hay in order that they had to fly away or die; and this may be done by day, if they are suspected and likewise he that hath a mosquito net may protect himself therewith (loc. cit.).

### (b) Distinctive characters

The general appearance of mosquitoes or gnats is familiar to most people. They are small insects (about 3–6 mm long) with long legs, a globular head, laterally compressed thorax and a long cylindrical abdomen. The wings are rather long and narrow and are carried flat over the back in repose. The antennae are somewhat hairy in the female and bushy in the male.

There are, however, certain non-biting midges which answer to this general description and which, like the mosquitoes, have aquatic larvae. Nevertheless, it is possible to recognize the true mosquitoes in both stages, without much difficulty, if they are carefully scrutinized. The characteristic features of the adult mosquitoes are as follows:

- (1) The mouthparts form a long, thin, projecting proboscis.
- (2) The wings bear tiny scales along the veins as well as a fringe of them along the hind margin. The wing venation, also, is characteristic. There are six longitudinal veins of which the second, fourth and fifth are forked.

The diagnostic features of mosquito larvae are:

- (1) There is a well-developed head followed by a swollen, unsegmented thorax.
- (2) They breathe atmospheric air through a pair of spiracles at the hind end of the body and almost always spend most of their time at the water surface with the spiracles through the water film.
- (3) There are tufts of bristles arising from many of the body segments.

### *Main types of mosquito*

Excluding the non-biting megarhine mosquitoes which are tropical in distribution (and medically unimportant) there are two main groups of mosquitoes, both represented in Britain.

- (1) The greater number of species, both in Britain and the world generally, belong to the *Culicine* tribe. Mosquitoes of this group do not transmit malaria though they can carry other tropical diseases such as yellow fever, filariasis and

*Anophelines*

*Culicines*

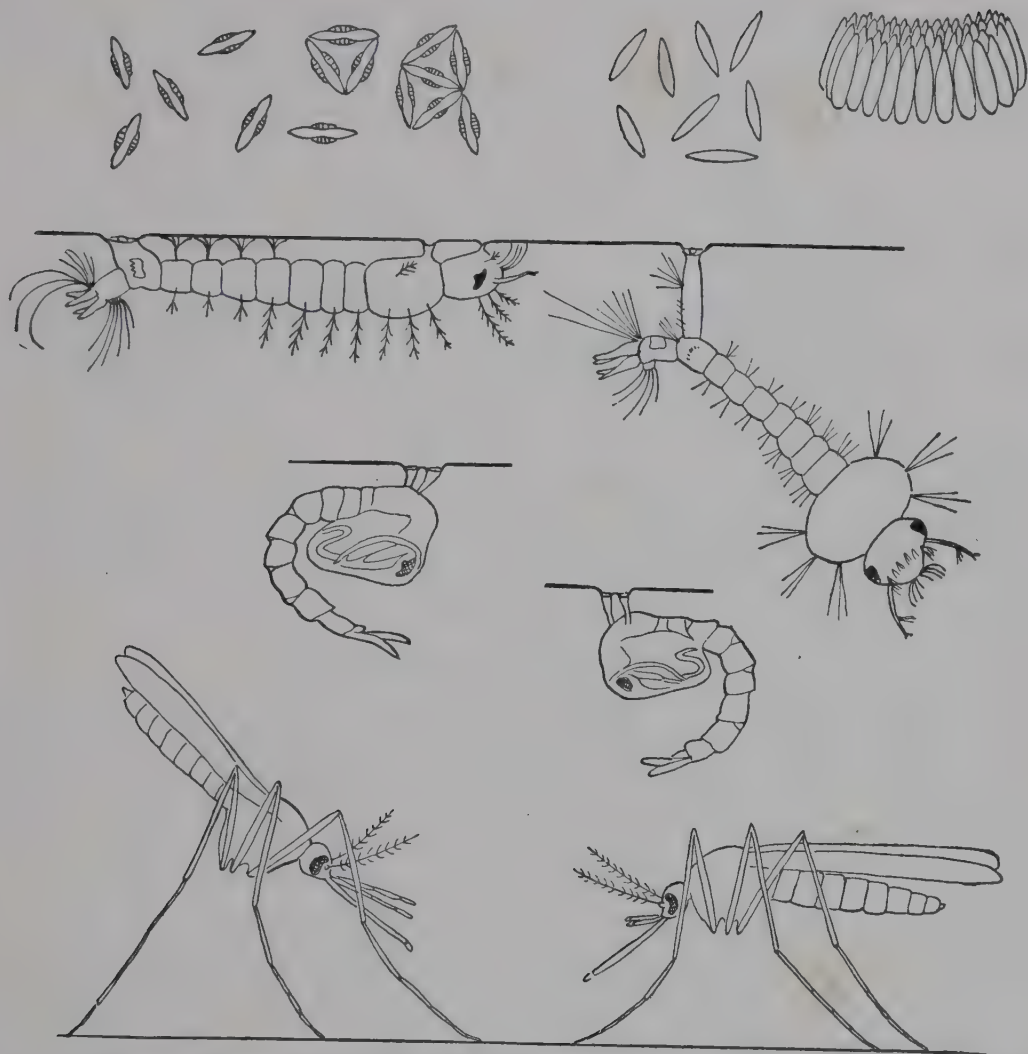


FIG. 17. Differences between anopheline and culicine mosquitoes in different stages of the life cycle. (After Marshall, *British mosquitoes*, Brit. Mus. (Natural History) 1938.)

dengue. These diseases are absent from Britain, but culicine mosquitoes can be highly objectionable on account of their vicious biting.

(2) The *Anopheline* mosquitoes constitute a considerably smaller group, almost all comprised within the single genus *Anopheles*. Owing to the part played by certain of them in transmitting malaria, they have been the subject of a great deal of research. In Britain they are not very liable to be troublesome on account of their bites alone; but they are occasionally responsible for secondary cases of malaria (see p. 200). It is therefore important to be able to recognize the type. Fortunately it is easily possible to do this with all stages of the development. The following table is illustrated by Fig. 17 and elaborated in the following section on life history.

Stage	<i>Anophelines</i>	<i>Culicines</i>
Eggs,	1. Provided with floats 2. Laid separately	1. No air floats 2. Sometimes stacked together in egg rafts

Stage	<i>Anophelines</i>	<i>Culicines</i>
Larvae	<ol style="list-style-type: none"> <li>1. Hind spiracles on the body surface (8th abdominal segment)</li> <li>2. Larva held up horizontally beneath water film by float hairs, etc.</li> </ol>	<ol style="list-style-type: none"> <li>1. Hind spiracles at the end of a tail-like tube or siphon (projecting from the 8th abdominal segment)</li> <li>2. Larva hangs down at an angle with only the tip of the siphon in the surface film.</li> </ol>
Pupa	Respiratory trumpets more conical	Respiratory trumpets more cylindrical
Adult	<ol style="list-style-type: none"> <li>1. Females with palps as long as proboscis</li> <li>2. No scales on abdomen</li> <li>3. Rest with proboscis and abdomen in a line, at an angle to surface</li> </ol>	<ol style="list-style-type: none"> <li>1. Females with short palps</li> <li>2. Abdomen covered with scales</li> <li>3. Rest with proboscis and abdomen forming obtuse angle, the abdomen more or less parallel with surface</li> </ol>

### Identification of species

Keys are provided in the Appendix (pp. 444-447) for distinguishing the more important (prevalent) British genera and species in the adult stage. A further key is for fully grown larvae of the four most important genera. Where there is doubt, specimens may be sent to an appropriate reference centre for identification (see p. 70).

### (c) Life history of mosquitoes<sup>(24)</sup>

The general appearance of some of the commoner mosquitoes is depicted in Figs. 18 and 19; but it must be admitted that only a very rough guide can be given from this type of illustration. The following notes on appearance of the various species may be of some assistance.

#### *Anopheles*

Mosquitoes of this genus can be distinguished as already described. The four commonest species are brown or dark brown with uniformly dark legs. *A. atroparvus* and *A. messeae* (formerly grouped together as *A. maculipennis*) have aggregations of dark scales on the wings, especially at intersections of certain veins, giving the appearance of dark spots (Fig. 18a).

*A. plumbeus* and *A. claviger* are also rather uniform in colour, except for a pale band down the thorax and a creamy-white tuft on the top of the head. Neither has spotted wings. They may be distinguished by colour, *A. plumbeus* being very dark brown, almost black, while *A. claviger* is moderately dark brown. The former species is also generally considerably smaller (Figs. 18b, 18c).

#### *Culex*

The two common house-haunting species, *C. pipiens* and *C. molestus*, are closely related and very similar in appearance (Fig. 18d). They are dull, brownish insects, the abdomen being dark brown with creamy-white bands at the base of each segment.

#### *Culiseta annulata* (Fig. 18e)

This is one of the largest and most common of British mosquitoes. The wings are spotted, like those of *Anopheles atroparvus* and *A. messeae*; but *Culiseta* can be

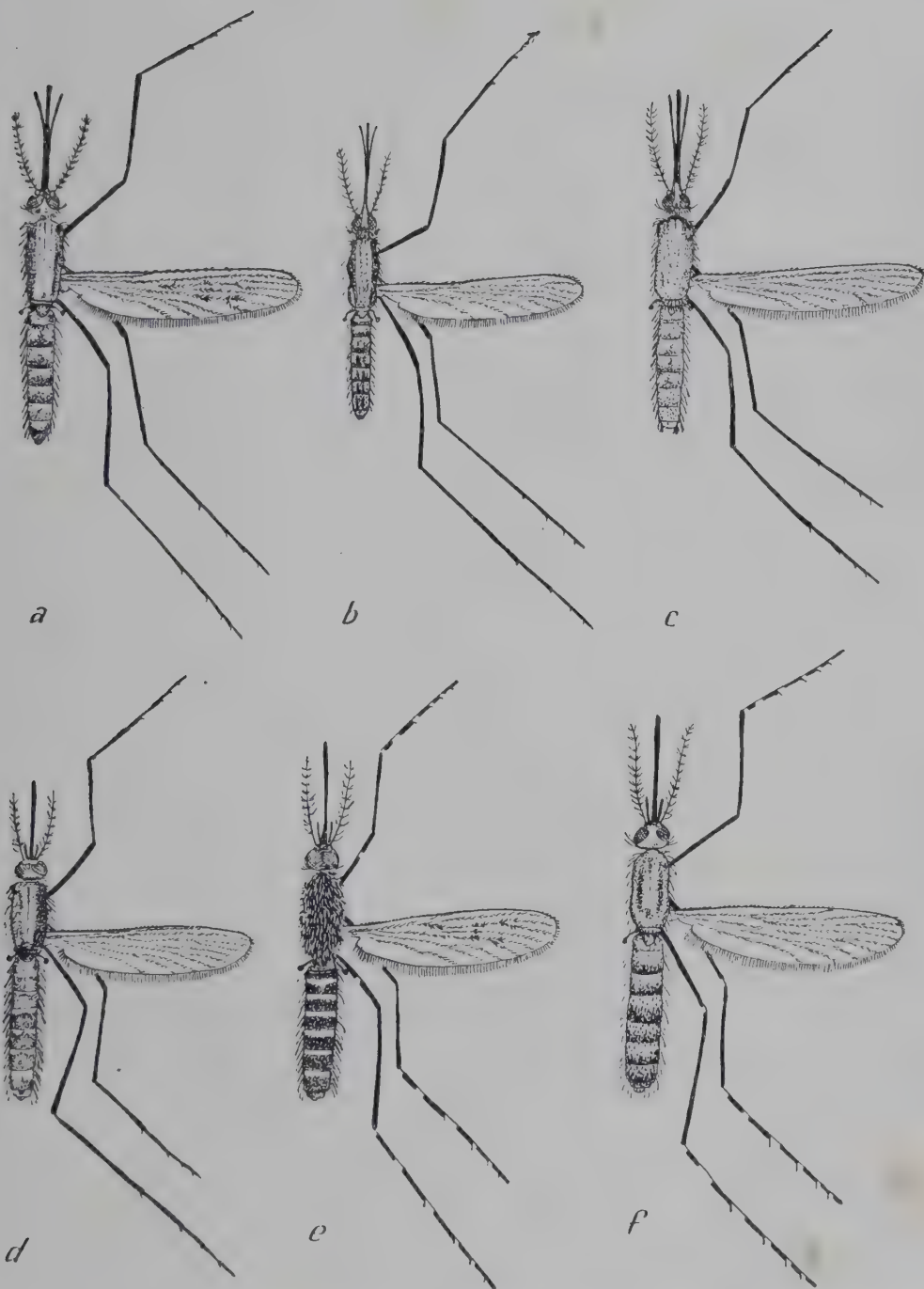


FIG. 18. Some common British mosquitoes. (a) *Anopheles maculipennis*; (b) *Anopheles plumbeus*; (c) *Anopheles claviger*; (d) *Culex pipiens*; (e) *Culiseta annulata*; (f) *Mansonia richiardi*. (After Edwards, Oldroyd and Smart, *British bloodsucking flies*, Brit. Mus. (Nat. Hist.) 1939.) Approx.  $\times 4\frac{1}{2}$ .

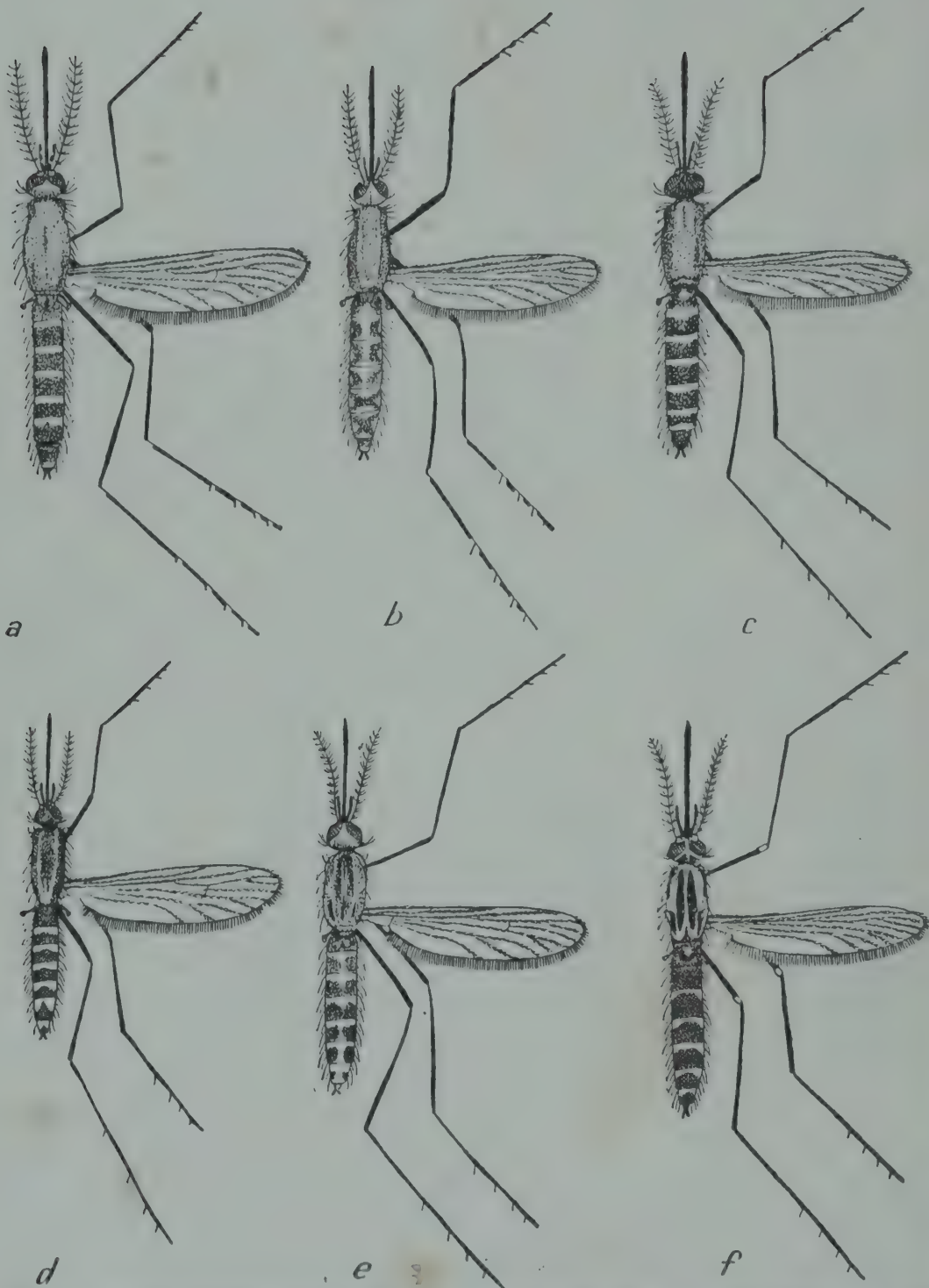


FIG. 19. Further common British mosquitoes. (a) *Aedes cantans*; (b) *Aedes caspius*; (c) *Aedes detritus*; (d) *Aedes punctor*; (e) *Aedes rusticus*; (f) *Aedes geniculatus*. (After Edwards, Oldroyd and Smart, l.c.) Approx.  $\times 4\frac{1}{2}$ .

easily distinguished, not only by its culicine characters, but by the bold black and white markings, especially the bands on the legs.

*Mansonia richardii* (Fig. 18f)

The general colour of this mosquito is brown; but among the dark scales of the abdomen and along the wing veins, there is a sprinkling of pale scales, giving a peppered appearance. The first segments of the tarsi carry (rather inconspicuous) pale rings in the centre as well as the base, a character shared only with *Culiseta*.

*Aedes*

As a rule, the mosquitoes of this genus are rather distinctly marked by patches of dark and light scales. Of the seven common species mentioned below, the following have light bands on the tarsi: *A. caspius*, *A. annulipes*, *A. cantans*. The first mentioned has pale scales on both sides of the joints, the other two on the base of the segments only. The other four species mentioned have uniformly dark legs.

*Aedes caspius* (Fig. 19b)

The thorax is bright fawn coloured with two longitudinal white stripes. The abdomen is brown, with a median longitudinal yellowish band and transverse yellow bands.

*Aedes annulipes* and *A. cantans* (Fig. 19a)

These two species are rather similar, with the thorax brown with small patches of pale scales and the abdomen transversed with pale bands. They differ in colouring, *A. cantans* being darker but relieved with white scales, whereas *A. annulipes* is moderately brown contrasting with yellowish scales.

*Aedes rusticus* (Fig. 19e)

This is a large mosquito (6-6.5 mm) bearing two longitudinal dark bands on the front of the thorax separated by golden-brown scales. The pale transverse bands on the abdomen widen in the centre to form a more or less continuous longitudinal stripe.

*Aedes punctor* (Fig. 19d)

The thorax is brownish and variable. The abdomen is distinctive in that the hind borders of the transverse pale bands are constricted in the centre, forming an inverted V.

*Aedes detritus* (Fig. 19c)

Though the tarsi are not ringed, the dark scales are sprinkled with pale ones. Pale scales are also sprinkled among the dark ones on the wing veins and abdomen, giving a peppered appearance. The thorax is a uniform brown and the abdomen carries transverse pale bands.

*Aedes geniculatus* (Fig. 19f)

Silvery-white spots at the tips of the femora contrast with dark scales to give an appearance of white 'knees'. The thorax has a distinctive white pattern and the abdomen has lateral triangles of white scales, contrasting with a dark background.

**Life history of mosquitoes****(i) Oviposition**

It will be convenient to begin a description of the life history with the egg-laying. Whilst all mosquitoes breed in water, the different species and varieties have a great number of individual preferences, ranging from small accumulations of water in rot holes in trees to large lakes and from salt marshes to mountain streams. The females seeking sites to lay their eggs display remarkable adaptive instincts in selecting appropriate places. Usually the eggs are laid on the surface of water, either from the edge, from the water surface or hovering above it. But certain species (of *Aedes*) lay eggs in shallow depressions on dry land which subsequently becomes filled with water at the appropriate season.

Eggs of anopheline mosquitoes are always laid separately on the water surface though they may occur there in large numbers. Some kinds tend to group themselves in triangles and other patterns owing to surface forces exerted by different parts of the egg. Certain culicines (genus *Culex*) have the habit of stacking the eggs together as they are laid (each egg being disposed vertically) and they adhere to one another, forming raft-like masses of perhaps several hundred eggs.

**(ii) Egg**

The eggs are spindle-shaped and about  $\frac{2}{3}$  mm long. Those of anophelines are canoe-shaped with lateral fan-shaped floats which distinguish them at once from culicine eggs. The egg surface sometimes shows characteristic markings which have proved of great value in identifying certain species of the *Anopheles maculipennis* group which are otherwise difficult to distinguish.

The eggs only hatch in water and those of many species cannot survive drying for more than a few days. Certain desert living species of *Aedes*, however, lay eggs which are said to remain viable for several years without water and to hatch within a day or two of being immersed in it; and British species of *Aedes* can likewise survive six months in the egg stage.

The duration of the incubation period in water depends on the species and the temperature, being generally of the order of a few days in the summer.

**(iii) Larva**

The larva has a head, a swollen thorax and a cylindrical abdomen composed of nine distinct segments. At various points there are tufts of bristles which are normally pinnate (or 'feathered') in anophelines and always simple in culicines.

The head of a culicine larva is decidedly wider than that of an anopheline, being nearly as wide as the thorax. Both types have pigmented simple eyes, short antennae and mouthparts with strongly toothed mandibles. On the labium are two

pronounced groups of bristles overhanging the mouth like a heavy moustache. These are known as the 'mouth brushes'.

The larvae have two methods of feeding. For most of the time the mouth brushes are actively vibrating and cause a current of water to flow past the mouth. Small organic particles present in the water (protozoa, bacteria, algae, fungal spores, pollen, etc.) become entangled in the maxillary bristles. From time to time a bolus of these small particles is passed into the mouth and swallowed. In addition to this method of feeding by filtration, the larvae can use their mandibles to nibble off bits of algae, plants and, occasionally, other larvae. For reasons to be described in a moment, the anopheline larvae feed with the head much closer to the surface film than the culicines.

Both types of larvae breathe atmospheric air from a pair of spiracles on the eighth abdominal segment. These spiracles penetrate the water film while the larvae are at the surface and when they dive they are protected by valve-like cover flaps. There is a great difference in the position of the spiracles in the two types of mosquito. In culicines they are borne at the end of a long tube-like projection called the siphon and the larva hangs obliquely head downwards from this tube with only the tip of it anchored in the surface film. In anopheline larvae the spiracles are nearly flush with the surface of the eighth segment and the whole dorsal length of the larva is held close to the surface film by star-shaped float hairs and other organs. The neck is very flexible so that the larva can turn its head right round and feed on organisms in the film directly above it. Thus, the characteristic positions of culicine and anopheline larvae hanging from the surface film are quite different and can be distinguished at once by the naked eye. The anophelines move about at the water surface in a series of jerks, tail first, whereas the movements of culicines at the surface are confined to wriggling. In addition, both forms, when alarmed, will break contact with the surface film and either sink or swim downwards with vigorous wriggling movements. Eventually, however, they swim up to the surface and renew contact with the air.

The last abdominal segment bears two bunches of bristles and four finger-like blood 'gills'. The function of these organs, however, seems to be regulation of osmotic pressure and not respiration.

There are four larval stages separated by four moults. After the last moult the pupal stage begins.

#### (iv) *Pupa*

The pupa is generally described as comma-shaped. The rather large dot of the comma is made up of the head and thorax while the tail is formed by the flexible abdomen. The rapid movements of this tail, which ends in a pair of paddles, enables the larva to dive with a series of jerky somersaulting movements, when alarmed. Normally the pupa, like the larva, remains at the surface film with its respiratory system in communication with the air through a pair of respiratory trumpets on the back of the thorax. (These 'trumpets' are more or less cylindrical in culicines but distinctly conical, widening apically, in anophelines.)

The fused head-thorax mass displays traces of the wings and long legs of the

adult insect which are developing inside. In the centre, between the rudimentary wings, is a large air cavity which gives buoyancy to the pupa and helps it to maintain its position at the surface.

At the end of the pupal period, the newly formed adult swallows some of the air from the central bubble and this enables it to swell and burst the pupal skin. The adult emerges from a dorsal split and rests for a short time (either on the discarded skin or on adjacent vegetation) until the adult cuticle has hardened with the wings expanded.

#### (v) *Adult*

The adult has a globular head, a large part of the surface of which is taken up by the compound eyes. The antennae, which are about three times as long as the head, are somewhat hairy in the female and quite bushy in the male; this provides a ready means of distinguishing the sexes with the naked eye. In both sexes the mouthparts are elongated into a proboscis, but those of the male do not include elements capable of piercing skin to suck blood. A pair of palps is present, one on each side of the proboscis. In the female, these organs are slender and smoothly scaled; those of anophelines being about as long as the proboscis while those of culicines are from one-fifth to one-half the length. The palps of males are usually ornamented with tufts of bristles; in all British species except one they are about as long as the proboscis. The palps of male anophelines are usually clubbed at the end while those of culicines are tapering and curl upwards.

Both sexes feed on various juices of fruits and flowers but the females also take meals of blood from vertebrates. The piercing mouthparts of the female are constructed as follows: the labrum forms a long narrow projection with the edges rolled under to form the sucking tube. Underneath runs the long narrow hypopharynx. The mandibles and maxillae are long blade-like stylets curved round this tube and adhere to it partly owing to an oily fluid which binds the parts together.<sup>(33)</sup> All these elements are carried in the trough of the elongated labium, which is U-shaped in section. The labium does not enter the wound, however, but as the piercing mouthparts penetrate the skin of the host, the labium gradually bends away from them but remains guiding them at the point of insertion 'like a billiard player thrusting with a cue'. Liquids are drawn up the food channel by the pumping action of enlargements in the pharynx. The alimentary canal runs back into the thorax where there are diversions into two dorsal and one large ventral blind sacs (the latter running back into the abdomen). There follows a sphincter valve guarding the entry to the flask-shaped midgut. When blood is taken (by female mosquitoes) it is admitted directly into the midgut; but when fruit juices are swallowed, they are stored temporarily in the blind sacs.

At the end of the midgut are the usual discharge ends of the Malpighian tubes, followed by a hindgut leading to the anus.

The thorax is narrow and deep with a characteristic hump-backed appearance. It is composed of three segments, as usual, but the delimitations between them are hard to make out. The greater part of the dorsal surface is formed by the shield-like scutum of the second segment which bears the wings.

The long thin legs are clothed in scales, sometimes forming light and dark bands of diagnostic value. The foot consists of a pair of minute claws which are simple in some genera and toothed in others.

The stances of the two varieties of mosquitoes are characteristic. Anophelines carry the abdomen in a line with the thorax and proboscis, at an angle with the surface on which they are resting, giving the impression that they are resting on their heads. Culicines, on the other hand, hold their abdomens more or less parallel to the surface; often the thorax is bent in a somewhat hump-backed attitude to achieve this. In both types the hind legs are often held in the air curving gently upwards.

The wings, as already mentioned, are ornamented with scales, not only as a thick posterior fringe, but also along the course of the veins. In action, the wings beat two or three hundred times per second and propel the insect at a rate of about  $\frac{1}{2}$  to 3 miles per hour.<sup>(19)</sup> In strong winds the mosquito does not attempt to fly. The dispersion of mosquitoes from their breeding sites depends to a large extent, as with the housefly, on the nature of the surrounding country. They are not insensate bodies dispersing at random but animals impelled by instincts to seek food and oviposition sites. Consequently the behaviour of different species depends on the feeding, breeding and egg-laying habits. There are records of mosquitoes invading ships as far as 15 miles away from land<sup>(43)</sup> so that they are able to traverse considerable distances over unfavourable territory. Mosquitoes in temperate climates are larger and fly farther than tropical species. Anti-larval measures against the latter in a circle of half a mile radius will usually be sufficient to protect the centre. In north-west Europe the corresponding distance is 2–3 miles.<sup>(10)</sup>

In addition to migration of mosquitoes by flight, they may be passively transported in vehicles, etc. One important result of this is that the development of regular air transport brings the risk of carrying mosquitoes or associated parasites into areas of the world where they are at present absent, although conditions may be entirely suitable for them to breed.

The abdomen, which is more or less cylindrical, is thickly covered with overlapping scales in culicine mosquitoes but only bears fine hairs in anophelines. There are ten segments, the last two being 'telescoped' inside the eighth. Protruding at the end of the female abdomen are a pair of cerci, which, however, are very small except in the genus *Aedes*. The males bear clasping organs for use in copulation. It is an interesting fact that the tip of the male abdomen rotates through  $180^\circ$  shortly after its emergence and remains upside down throughout its adult life.

Like certain other small flies, most species of mosquitoes perform a nuptial dance before mating. The 'dance' is performed by a number of males (from a few to several thousand, according to species) rising and falling in the air in a stationary swarm. This commonly occurs out of doors in the evening but certain species will dance in quite small cages in a laboratory and even mate without swarming. The females fly into the swarm and copulation takes place in the air; it lasts from a few seconds up to a minute. Females will pair before taking a meal and store the spermatozoa they receive in a special sac ('spermatheca') for subsequent egg-laying.

A single impregnation may suffice for many batches of eggs laid over a period of many weeks.<sup>(35)</sup>

#### (d) Quantitative bionomics of mosquitoes<sup>(1)</sup>

Mosquitoes which can be reared in the laboratory show the usual response of an increased speed of development with a rise in the temperature. The following figures are average incubation periods for the American *Anopheles quadrimaculatus*.<sup>(16)</sup>

1.6	days	at	28°C (82°F)
2.3	„	„	23°C (73°F)
4.5	„	„	18°C (64°F)
15	„	„	12°C (54°F)

The total development of *An. atroparvus* was observed to depend on temperature as follows.<sup>(3)</sup>

12 to 15	days	at	34°C (93°F)
18 to 19	„	„	24–30°C (77–86°F)
23 to 35	„	„	15–18°C (59–64°F)

In nature, the relation of life history to climate is complicated by different ways of passing the winter and by egg-laying habits.

The changes in population density at different seasons of the year must vary a great deal in mosquitoes of different breeding habits. Obviously species that select specialized breeding sites such as rot holes in trees cannot have the same potentialities for increasing in numbers as forms which breed in lakes or marshes. In general there is an enormous increase in adults during the summer months. By releasing marked mosquitoes and estimating the total population from the proportions recaptured, American workers have assessed the populations of adult *An. quadrimaculatus* to be of the order of 10,000 to the acre, in summer months in an area in Tennessee.<sup>(7)</sup>

It is rather difficult to decide what are the effective checks to growth of mosquito populations. The actual area of suitable breeding water of the right pH, saline content, and so forth, may be important; in most ponds, food supply seems unlikely to be a serious limitation since the larvae can feed on so many things. Throughout life mosquitoes are subject to attacks by different predators. The larvae are eaten by predaceous aquatic insects and by fish. (Small fish of the genus *Gambusia* have been successfully used to control them in suitable places.) The adults are caught and eaten by dragon-flies, wasps and various predaceous Diptera besides birds and bats. In the laboratory, adults may live for several months with regular opportunities for feeding, and egg-laying, but their length of life under natural summer conditions is problematical. In recent years, however, much has been learnt about the age of wild female mosquitoes, from dissections which reveal how many times they have laid egg batches.<sup>(6)</sup> The cycle of feeding and egg-laying in *Anopheles maculipennis* takes about 4 days in temperate regions around 20°C (68°F). In the

vicinity of Moscow, most of the specimens caught in the summer months had completed only 1 or 2 cycles and very few had more than 5 or 6 egg batches. Apparently, the average age was about a week with very few more than 3 weeks old.

(e) **Biology of various types of mosquito**<sup>(27)</sup>

In the following sections, the occurrence of the various stages of mosquito in different months of the year will be indicated by a formula suggested by Marshall, thus E = eggs, L = larva, A = adults and H = hibernating adults. The figures in brackets give the months during which these various stages can be found.

ANOPHELINES

*Anopheles atroparvus* *Anopheles messeae*

These two related species are closely similar in appearance and habits and were formerly included in the species *Anopheles maculipennis*. The adults are difficult to distinguish, but the two forms can be recognized from the surface pattern of the egg.

**Biting habits.** Both species commonly rest in animal shelters and bite domestic animals, such as pigs, cattle, rabbits; and *A. atroparvus* is also prone to bite man. In the winter, *A. messeae* retreats to some unheated shelter and goes into complete hibernation (i.e. diapause; see p. 57; whereas *A. atroparvus* continues to bite at rare intervals, a matter of some importance (see p. 200).

**Breeding sites.** Both species breed in sunlit water, especially where there is abundance of aquatic vegetation and where green algae, such as *Spirogyra*, are plentiful. *A. atroparvus* distinctly prefers brackish water (as in coastal swamps), whereas *A. messeae* is restricted to fresh water.

**Distribution.** '*A. maculipennis*' has been recorded throughout Britain; but *A. atroparvus* is restricted to coastal areas and *A. messeae* to fresh water, inland sites.

**Seasonal occurrence.** H (9-5), E (4-9), L (4-9), A (6-9).

*Anopheles plumbeus*

This mosquito is present throughout the British Isles in parks and woodland country. The bites are not painful, but on a few occasions they have been the cause of indigenous malaria.

**Breeding places.** This is a sylvan species, which breeds in the water in rot holes in trees, never in lakes or ponds.

**Distribution.** The species is present throughout Britain in parks and woodland country.

**Seasonal occurrence.** E (1-12), L (1-12), A (5-9).

*Anopheles claviger*

This is a mosquito which virtually always bites out of doors, being occasionally troublesome to people sitting in gardens or working in allotments, etc. It breeds in water tanks, ponds and cisterns as well as ponds and lakes. Since it overwinters as larvae, it is advisable to treat well-established breeding sites in early spring before any adults emerge.

**Distribution.** Common throughout Britain.

**Seasonal occurrence.** E (5-9), L (1-12), A (4-9).

## CULICINES

(i) Genus: *Culex**Culex pipiens*

This brownish, nondescript mosquito is probably the best known since it so commonly hibernates indoors. It feeds almost exclusively on birds and frogs and apparently never bites man, though it often gets the blame for bites of more evanescent mosquitoes.

*C. pipiens* breeds readily in small static collections of water exposed to daylight; very commonly in rainwater butts, for example. In the autumn, adults enter unheated rooms of houses or outhouses to hibernate.

*Distribution.* Common throughout Britain in rural areas.

*Seasonal occurrence.* E (4-10), L (4-11), A (5-9), H (9-4).

*Culex molestus*

The two species *C. pipiens* and *C. molestus* are very closely related and extremely difficult to distinguish. On the other hand, their habits are very different. Whereas the former does not bite man, *C. molestus* is a vicious biter. It breeds mainly in underground collections of water (e.g. in cellars) and it is largely urban in distribution in Britain. Occasionally it has been a troublesome nuisance in underground railways, breeding in sumps under the platforms and biting passengers and staff. It prefers not to hibernate and continues to breed slowly throughout the winter.

*Distribution.* North, south and south-east England. Occurs in urban areas, where there are collections of water below ground.

*Seasonal occurrence.* E (1-12), L (1-12), A (1-12).

(ii) Genus: *Culiseta**Culiseta annulata*

*C. annulata* is a sporadic pest in different parts of the country. In summer it bites freely out of doors in gardens, etc.; in winter it will attack man in mild weather and not infrequently enters houses to do so. It will breed in a wide variety of places, from the clear water of grassy lakes, to drainage from manure or sewage works; in stagnant brackish water near the coast or in small ponds, cisterns and water butts. On the whole, polluted water is preferred and, where there is a nuisance from the bites of this mosquito, stagnant water nearby should be searched for the larvae.

*Distribution.* Common throughout Britain.

*Seasonal occurrence.* E (4-10), L (1-12), A (4-11), H (11-3).

(iii) Genus: *Mansonia**Mansonia richardii*

This mosquito bites man readily and may constitute a severe nuisance when numerous. Usually they remain hidden in vegetation until dusk and then emerge in search of a blood meal. If there are houses within a hundred yards or so of a breeding site, these mosquitoes may enter bedrooms to take a blood meal and leave again before dawn.

*M. richardii* belongs to a group of culicine mosquitoes with an unusual breeding

habit. The eggs are laid on the underside of leaves of aquatic plants. The larvae resemble normal mosquito larvae except that the breathing siphon ends in a kind of tooth which is inserted into stems of aquatic plants and draws air from them. The plants commonly attacked are those of the genera *Ranunculus*, *Acorur*, *Glyceria* and *Typha*. The pupae have the same habit, so that neither stage rises to the surface to breathe. The mature pupae detach themselves from the plants, rise to the surface and finally the adults emerge.

*Distribution.* Throughout Britain, wherever suitable breeding grounds occur.

*Seasonal occurrence.* E (6-9), L (1-12), A (5-9).

#### (iv) Genus: *Aedes*

This is a prolific genus with numerous successful species, 14 of which occur in Britain. Mosquitoes of this genus are notable for laying eggs in damp soil, hollows of trees, etc., in places likely to fill with rain subsequently. The eggs develop but do not hatch until immersed in water weeks or months later.

Several species cause severe annoyance from their bites in Britain. They can be divided into two groups according to the breeding sites chosen.

#### (1) SYLVAN SPECIES

*Aedes cantans*            *Aedes punctor*  
*Aedes rusticus*        *Aedes annulipes*

This group of mosquitoes occurs in and around woodland. The breeding sites chosen, range from exclusively shaded pools (*A. cantans*); ponds and ditches partly shaded (*A. rusticus*, *A. punctor*); to more open pools on heaths and the edges of woodland (*A. annulipes*). Adults are mainly troublesome in the vicinity of the breeding grounds.

All four species have only one generation a year in Britain. *A. rusticus* overwinters in the larval stage; but the other three species pass most of the winter as eggs which only hatch in the early spring.

*Distribution.* All four species occur throughout the country in suitable areas.

#### *Seasonal occurrence*

*A. rusticus:*    E (5-10), L (9-4), A (4-10).  
*A. cantans:*    E (1-12), L (2-5), A (4-9).  
*A. punctor:*    E (1-12), L (1-4), A (4-9).  
*A. annulipes:* E (1-12), L (2-5), A (4-9).

#### (2) SALT MARSH SPECIES

*Aedes detritus*    *Aedes caspius*

Both these forms prefer to breed in brackish water (though *A. caspius* will also develop in fresh water); consequently they are only numerous in coastal districts. Nevertheless, they are together responsible for most of the severe biting nuisances caused by British mosquitoes. The trouble is augmented by the fact that they readily attack people 2 or 3 miles from the breeding grounds.

*Distribution.* Both occur in coastal districts throughout the country, though more commonly in the south. *A. caspius* occurs to a limited extent inland.

*Seasonal occurrence.* Unlike the sylvan *Aedes* mosquitoes, the salt marsh forms produce several generations during the summer months.

*A. detritus:* E (1-12), L (1-12), A (1-12).

*A. caspius:* E (1-12), L (4-9), A (4-10).

## (f) Importance

### (i) Malaria

Although most anopheline mosquitoes can be made to transmit malaria experimentally, only about a score out of some 160 species are serious vectors in different parts of the world. The essential characteristics of a serious malaria situation are now well understood and some attempts made at their comparative evaluation. The basic essentials are as follows: (1) the human population must include individuals carrying active parasites; (2) there must be rather large numbers of anopheline mosquitoes with the habit of biting man; (3) the mosquitoes must live long enough for the parasite to mature in them and become infective.

Each of these points needs consideration.

(1) Malaria formerly occurred in various parts of Europe, including the Netherlands, so it was always possible for the infection to be introduced into Britain. Unless other circumstances were favourable to the disease, however, it would not persist. After it had died out (for reasons to be discussed shortly) invasions of infected men occurred twice in the present century; these were returning soldiers after the two world wars. As a result, there were temporary waves of malaria transmitted by indigenous mosquitoes. But there was never any serious probability of the disease becoming established here again.

(2) Many anopheline mosquitoes will bite man in addition to other animals, but very few actually prefer to do so. To transmit malaria, an anopheline must bite an infective human and then bite another one after a space of time. The chances of this happening are sharply affected by the insect's willingness to take human blood.

In England, no anopheline actually prefers to bite on man; but one species, *Anopheles atroparvus*, likes to settle in houses and animal quarters and bite man as well as domestic animals. During the winter, this mosquito remains indoors, but does not hibernate completely. Consequently, if it remains in a dwelling, there are repeated opportunities for human blood meals. This species seems to have been the main vector of malaria in the past and areas of England where ague (malaria) was common, correspond to its distribution. Most of the cases of malaria transmitted from troops in the present century occurred in the same region.

(It should, however, be mentioned that several recent cases (some fatal) were carried by another mosquito, *Anopheles plumbeus*. This breeds in rot holes in trees and occurs in parks and gardens, even in or near cities, and bites people in the open.)

(3) The life-span of a mosquito in nature is difficult to determine, but from the evidence available it appears to be of the order of a week or two. This is not greatly different from the time required for the malaria parasite to become infective. This, of course, reduces the chances of transmission. In many tropical countries, the incubation period is shorter and the large numbers of man-biting mosquitoes make

up the losses due to mortality, so that transmission is maintained and often increases. In Britain, however, the cool climate increases the incubation span; indeed, below 15°C (60°F) development of the parasite is prolonged indefinitely. Furthermore, there are fewer anophelines regularly biting man, so that transmission is much more unreliable.

The foregoing remarks summarize the reasons why malaria in England was always a marginal disease on the limits of its range. It appears that the reasons for its extinction in the last 200 years were improvements in farming and rural housing. Drainage reduced the available breeding sites and increases in cattle, pigs and other livestock diverted the mosquitoes from biting man. At the same time, better houses denied them the dark cobwebby corners in which mosquitoes prefer to rest, so that they now congregate mostly in cattle sheds, pigsties and rabbit hutches.

### (ii) Annoyance from bites

#### *Species responsible*

No British mosquito feeds exclusively on human blood, but different species vary in the avidity with which they will do so. Some forms attack man viciously if the opportunity arises; on the other hand, the common house gnat, *Culex pipiens*, lives in close association with man but will not bite him.

Only a limited number of British mosquitoes will bite indoors. They are *Culex molestus*, *Anopheles atroparvus*, *An. messeae*, *An. plumbeus*, *Culiseta annulata*, *Mansonia richardii* and (rarely) *Aedes punctor*. Of these, the first three rarely or never bite out of doors, whereas the others are frequently troublesome in the open, especially in the evening. Some of them only enter houses for a short time, often at night, and leave after biting. It may happen that the harmless *Culex pipiens*, which remains indoors, is blamed for the bites.

Some of the most persistent and troublesome biters are associated with particular types of breeding ground. Thus, the sylvan species, *Aedes rusticus*, *A. cantans*, *A. punctor* and *A. annulipes*, all bite in and around woodland. *Anopheles plumbeus* is also associated with parks and woodland. Another type of breeding ground is the salt marsh in coastal districts, which may produce annoyance from *Aedes caspius* or *A. detritus*. All these are rural; in contrast, *Culex molestus* has a rather sporadic distribution, often in large towns.

#### *Type of reaction*

It is well known that some people suffer more than others from mosquito bites, even when exposed to the same degree. This is commonly believed to be due to the mosquitoes biting the sufferer and avoiding the other person. There is, in fact, evidence that mosquitoes show slight preferences for feeding on particular individuals; but it is extremely rare for one person to be heavily bitten and another, in the same environment, to be avoided entirely. In most cases the apparent differences in mosquito attacks are due to differences in reaction to the bites; some people suffer badly while others may not realize they have been bitten.

The reaction to a mosquito bite is allergic in nature; it is a response of the body to foreign proteins introduced with the mosquito's saliva. Apparently, sensitization

develops in stages, in susceptible people.<sup>(26)</sup> After a short exposure to regular biting, a delayed reaction begins to occur, about 24 hours after the bites. This consists of a papule surrounded by reddening and swelling and attended by severe itching. It may persist for several days and the scratching induced may give rise to secondary infections. Continued exposure to biting induces another immediate reaction in the form of a weal; this, however, disappears within an hour and is succeeded by the delayed reaction next day. Further experience of biting may result in desensitization, which is a common experience of people living in the tropics and regularly exposed to bites. The first to disappear is the delayed (and more unpleasant) reaction; subsequently the immediate weal may not develop and the person becomes completely immune.

For the relief of mosquito bites any soothing or analgesic lotion or ointment can be used. At one time, anti-histamine cream rubbed on the site soon after biting was thought to reduce pruritus. But more extensive trials suggest that the apparent benefit was due to massaging with the cream.<sup>(23)</sup>

Sufferers from bites should try to avoid scratching, which may cause secondary infection.

### (g) Control measures

#### *General*

Control measures may be directed against the adult or larval stages of mosquitoes. For malaria suppression in tropical countries, the practice of spraying inside all dwellings has achieved excellent results. It seems unlikely, however, that such measures would be justified in Britain, where outdoor annoyance from bites is the main problem. (Even where residual sprays are applied, they may not prevent biting, though if they kill mosquitoes resting on the wall after a meal, the malaria transmission is prevented.) Mosquitoes which enter bedrooms in Britain to bite may perhaps be combated by the use of an aerosol spray in the evening.

For temporary control of outdoor breeding grounds, the use of larvicides (as described on pp. 133-136) would be suitable. Alternatively, permanent control by drainage may be possible in some cases. Before appropriate control measures can be decided upon, it is essential to identify the species responsible for the nuisance. The known habits of the mosquito should then enable the breeding grounds to be discovered and an inspection will reveal what is feasible.

If radical control measures are not possible, the use of repellents (pp. 113-114) may be desirable, especially for people who suffer badly from mosquito bites.

#### *Special points*

##### (i) *Domestic species*

Hibernating mosquitoes such as *Anopheles atroparvus*, *An. messeae* and *Culiseta annulata* can be attacked, with advantage, indoors by aerosols containing pyrethrins or DDT, etc. They may also be destroyed to a large extent by cleaning measures such as lime-washing in animal quarters and sheds.

The non-hibernating *Culex molestus* may also be attacked, in the adult stage, by

aerosols. But it is equally important to trace the breeding sites, which are also likely to be indoors underground.<sup>(36)</sup> Once the breeding foci have been traced they can be easily dealt with by drainage or larvicides.

(ii) *Sylvan species*

The four common sylvan species are *Aedes rusticus*, *A. cantans*, *A. punctor* and *A. annulipes*. All of them are single-generation mosquitoes; but whereas *A. rusticus* can be found throughout the winter, the others remain in the egg stage until January or February. By April, the *A. rusticus* are beginning to emerge as adults. Therefore, anti-larval measures against all four should preferably be done in March. Later in the season, when all are present in the adult stage, larvicides are useless. At this point, only repellents can be used, until the following spring. Alternatively, the mosquitoes can be avoided, as they do not fly far from the breeding sites; this should be remembered in choosing camping sites.

(iii) *Rot hole species*

Rot holes in trees are by no means negligible as breeding places for certain species, the most suitable spots being cavities formed in the trunk where a branch has fallen off. Trees most liable to contain such cavities are beech, sycamore, horse chestnut and elm. The holes can be simply dealt with by filling with earth or concrete (e.g. *Anopheles plumbeus*; *Aedes geniculatus*).

(iv) *Pond and lake breeders*

Extensive lakes with deep water are not likely to be prolific breeding places except round the margins unless they contain floating vegetation. Clearance of such vegetation exposes the larvae to attacks of small fish and other natural enemies and largely reduces the nuisance. Removal of aquatic vegetation is especially important for eliminating *Mansonia richardii*, which obtains its oxygen from the stems of such plants. (Since these larvae do not need to surface for air, they are immune from many superficial larvicides.)

As regards the more ordinary pond-dwelling mosquitoes, with several summer generations (e.g. *Anopheles claviger*, *An. atroparvus*, *An. messeae* and *Culiseta annulata*), it may be necessary to make anti-larval treatments at about fortnightly intervals through the summer. With only one generation a year (e.g. *Aedes cinereus*) it is necessary to complete larval control in March, April.

(v) *Salt marsh mosquitoes*

Since these mosquitoes may cause a nuisance at a considerable distance from their breeding grounds, it is essential to identify them and to trace the actual breeding sites. Local action against larvae of harmless mosquitoes (e.g. *C. pipiens*) is time wasted. Persistent attacks of mosquitoes near the coast should always arouse suspicion of salt marsh *Aedes*. The types of breeding place may include stagnant water behind broken and leaky sea walls or ineffective sluice gates which allow incursion of sea water at high tides. Flooded golf bunkers, borrow pits or disused gravel pits near the sea should also be inspected.

Wherever possible such breeding sites should be eliminated, either by drainage, mending of sea defences or by filling in small depressions. In some cases, where extensive brackish marshes are involved, the problem may require expert engineering advice.

Comparatively small breeding sites can be treated with larvicides. But, since there are several summer generations of these mosquitoes, regular monthly treatments will be necessary, preferably from February till October.

### III·NON-BITING MIDGES

This is perhaps a convenient place to give a short account of certain non-biting midges with a general resemblance to mosquitoes. All of them belong to the group Nematocera and are more or less closely related to the Culicidae.

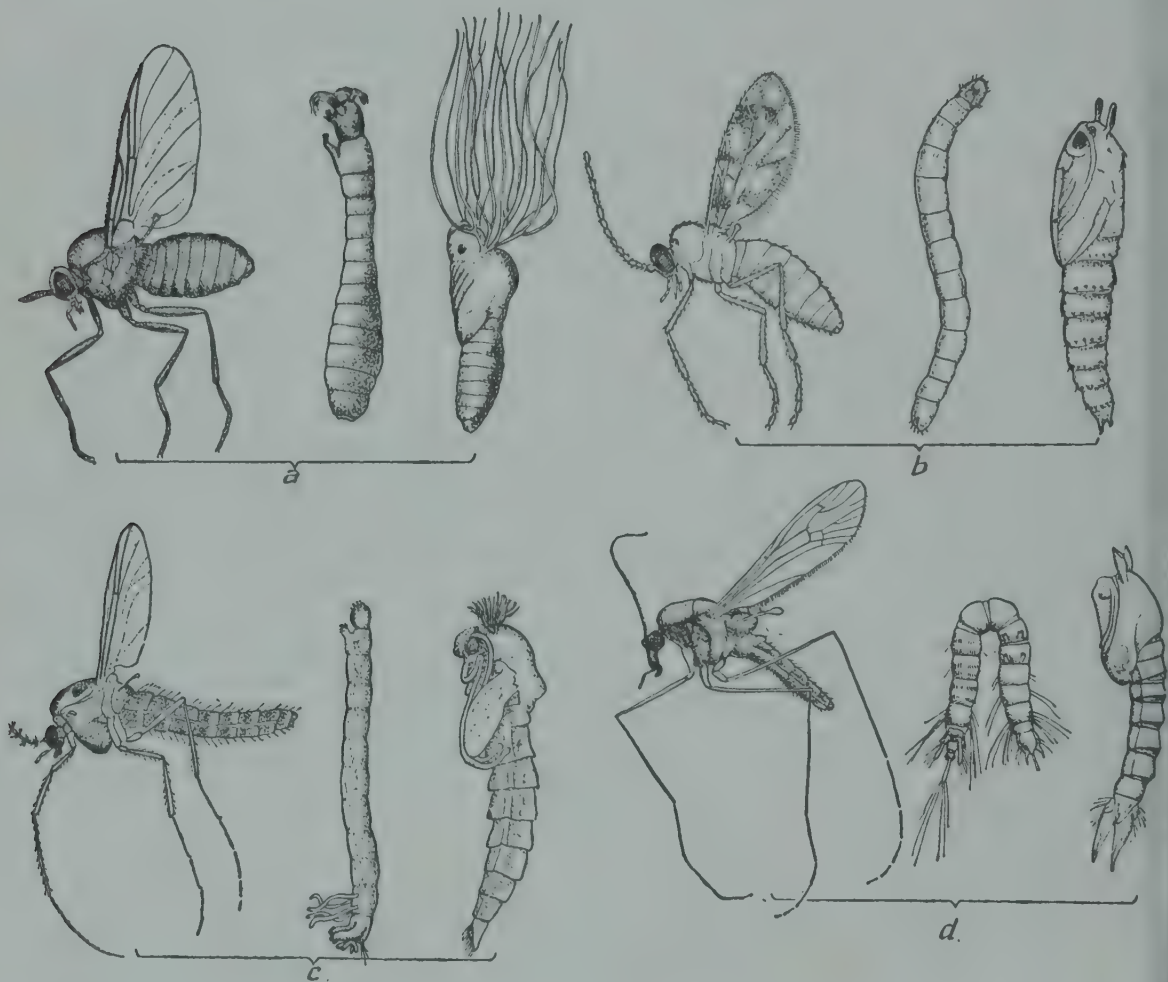


FIG. 20. Midges with aquatic larvae. (a) & (b) biting; (c) & (d) non-biting. (a) *Simulium ornatum* (after Smart, l.c.); (b) *Culicoides impunctatus* (after Hill, *Ann. trop. Med. Parasit.* (1947) 41, 55); (c) *Chironomus* sp. (partly after Miall and Hammond, *The harlequin fly*, 199); (d) *Dixia* sp. (after Seguy (1925) *Faune de France* (No. 12). (a) A  $\times 7$ , L & P  $\times 4$ ; (b) A  $\times 10$ , L  $\times 7$ , P  $\times 16$ ; (c) A & P  $\times 4$ , L  $\times 3$ ; (d) A  $\times 10$ , L & P  $\times 7$ .

(a) **Midges** (Chironomidae) (Fig. 20c)

The superficial appearance of these fragile little flies is similar to that of mosquitoes, but they may be distinguished by the following characteristics: (1) The proboscis is short. (2) The wings are bare or carry hairs, never scales.

These flies may be seen in large numbers during the summer months swarming in the vicinity of the ponds, lakes, or streams in which they breed. These swarms consist mainly of males 'dancing' in the air apparently as a preparation for mating; after copulating the pairs fly out of the swarm.

The females lay large numbers of eggs (sometimes over 1000) in a gelatinous mass. Those of some forms are attached to various objects just below the surface of the water; in others they are found at the bottom of the water. The larvae are cylindrical in form without the large swollen thorax of mosquito larvae. They are usually provided with two pairs of pseudopods or false legs, one pair on the thorax and the other on the last body segment. Some construct mud tubes in which they spend most of the time; others live freely in the mud surface or swimming in the water. Unlike mosquito larvae, they have a closed respiratory system and do not need atmospheric air; instead they absorb oxygen dissolved in the water through small 'gills'. The mud-dwelling forms of some species of *Chironomus* are blood-red owing to the presence of haemoglobin in their blood (which assists their respiration in periods of oxygen deficiency). Other larvae are colourless or greenish, probably owing to algae consumed as food. The pupae of some forms remain quiescent on the bottom mud until ready to emerge; others are quite active. The total life cycle occupies about 3 to 4 weeks in summer.

Chironomids may become a nuisance in two ways:

(1) Sometimes the worm-like larvae pass through reservoir filters and get into pipes carrying drinking water. This sometimes gives rise to considerable alarm, especially if they remain alive and wriggling vigorously. Though unpleasant, they are harmless. Control in such cases is usually done by attention to the filters which must be deranged in some way to permit the passage of the larvae.

(2) It may happen that large swarms of adults may constitute a nuisance in public gardens or parks. An interesting example was provided by the lakes artificially prepared for the 1939 New York World Fair. These lakes, which were created by inundating large areas of salt marshes, provided prolific breeding sites for various chironomids. Control was eventually obtained by five monthly sprayings of ortho-dichlorobenzene at 16 gallons, or trichlorobenzene at 13 gallons, per acre.<sup>(8)</sup> The insecticides were sprayed undiluted from nozzles under the water carried by a special launch.

(b) **Dixa midges** (Dixidae) (Fig. 20d)

The adults of this small family can be distinguished from mosquitoes by their short proboscis and the absence of scales on the wing. Unlike the Chironomidae (as well as the Culicidae) their antennae are filiform and bare of hairs. Also, the anterior wing veins show a strong curve near the tip of the wing.

The eggs are laid in jelly masses attached to submerged objects, usually in ponds containing a good deal of vegetation. The larvae are cylindrical in form, without a

swollen thorax, and they characteristically assume a U-shaped position. They remain close to the water surface and bear a pair of spiracles, surrounded by water-repelling hairs which are normally kept above the water film. They can, however, submerge completely. Quite often they are found in the water film covering partly submerged leaves or stones. The pupae, which are rather like those of mosquitoes, wriggle out of the water before the emergence of the adults.

### (c) **Phantom midges** (Choaboridae)

This family is very often included in the Culicidae as a sub-family. The adults are rather similar to mosquitoes but lack the long proboscis. The wings bear scales in the hind margins but very few or none along the veins.

The young stages exhibit considerable diversity. Eggs may be laid singly or in masses. The larvae of some forms come to the surface to breathe and certain species bear a short siphon. Other varieties are not dependent on atmospheric air. Most of these larvae are curious, transparent creatures, which are quite difficult to see even in clear water. Usually all that can be seen are two dark eye-spots and two hydrostatic air bladders at each end of the body. These larvae are predaceous and seize their prey by a pair of prehensile antennae. The antennae bear strong spines at the top which enables the larvae to be distinguished from those of mosquitoes.

## IV · BITING MIDGES (Ceratopogonidae)

### (a) **Distinctive characters** (Fig. 20b)

The very small midges concerned were formerly included with non-biting midges in the family Chironomidae, but it is now generally agreed that they conveniently fall into a natural group between that family and the Simuliidae. They are more or less intermediate in build, having shorter legs and broader wings than Chironomidae but a more slender body than the Simuliidae. The females all possess sharp biting mouthparts like the universally bloodsucking Simuliidae though only a proportion of them (belonging to three genera) are known to attack birds and mammals. On the other hand, the non-biting males resemble those of Chironomidae and Culicidae in having bushy antennae, whereas those of Simuliidae are bare in both sexes.

### (b) **Life history**<sup>(14, 18, 25)</sup>

There is considerable diversity in life histories shown by members of this family. The breeding sites are often aquatic, some species preferring salt waters, others being limited to foul and stagnant waters and some to fresh flowing streams. Other species live in mud, humus or even damp rotting wood. The eggs are laid singly or in small groups, sometimes in echelon.

#### *Egg*

The egg is cigar-shaped, about 0.3 to 0.5 mm long and covered by longitudinal rows of small mushroom-shaped processes, giving a ridged appearance. Pale when laid, the eggs darken within half an hour.

*Larva*

The larva has an oval pale brownish head and a long cylindrical segmented body, dull-whitish or translucent. It is devoid of appendages, lacking even the false legs or pseudopods of a typical chironomid larva, but moves with a wriggling eel-like motion. Many of the important species live in mud, sometimes at a particular depth. Thus, *C. impunctatus*, *C. obsoletus* and *C. pallidicornis* occur in the upper 2 inches, whereas *C. heliophilus* is found below this. In all members of the family, respiration is entirely through the cuticle, spiracles being absent. The food is apparently algae, protozoa and similar small forms of life.

*Pupa*

Larvae generally leave the water or crawl to a drier region to pupate. The pupae are provided with a pair of respiratory trumpets on the back of the thorax (like mosquito pupae) and they breathe atmospheric air. As usual, among flies of this general type, the adults finally emerge through a split in the back of the thorax.

*Adult*

The adults are all very small, dark-coloured flies with a wing span of 2–3 mm (Fig. 20b). The head bears well-developed compound eyes and moderately long antennae, hairy in the female and bushy in the male. The mouthparts<sup>(17)</sup> are considerably shorter than those of mosquitoes, but they include similar elements which, in the female, are likewise adapted for piercing. These comprise – labrum (overlip), mandibles, maxillae and hypopharynx; a pair of jointed maxillary palps and an elastic labium (see Fig. 22b). The labium does not enter the wound, but behaves like its counterpart in the mosquito, guiding and supporting the piercing elements. Feeding is rather rapid and only occupies about three minutes. The males have similar mouthparts, but the mandibles and maxillae are smaller and weaker.

These midges bite throughout the day and night but especially at dawn and dusk. They are particularly troublesome in warm, calm weather and severe attacks often occur in slight drizzling rain. As a rule they do not fly far from the breeding grounds so that attacks are fortunately restricted to these areas.

**(c) Quantitative bionomics**

A few species of *Culicoides* have been reared in the laboratory. The durations (in days) of the various stages were as follows:

*C. impunctatus* at 16–19°C: E (7–20, av. 14), L (approx. 150), P (5).

*C. obsoletus* at 16–19°C: E (approx. 17), L (approx. 100), P (5).

*C. nebeculosus* at 15–20°C: E (3–6), L (20–60 spring and 40–125 autumn), P (4–7).

In the field development was considerably slower, there being usually only one generation a year. Near Liverpool, adults (and presumably egg-laying) of *C. impunctatus* are at a peak from mid-May to July. Early larval stages are found in the soil in summer and they overwinter as fourth stage larvae which pupate in the following April. In the same area, *C. obsoletus* adults have two peaks of abundance, in May–July and September–October. This is probably due to a second summer generation.

Near London, *C. vexans* eggs, laid in July and kept in the open, did not hatch for  $4\frac{1}{2}$  months. The subsequent larval stage lasted 6 months, but the pupal period was only 4 days.

The females of *C. impunctatus* lay about 50 eggs each, on the average. In favourable areas as many as 50,000 of the adults per acre may be simultaneously active at the season of maximum prevalence.

#### (d) Importance

Biting midges in Britain do not carry human disease but they are responsible for the transmission of a filarial infestation of horses which causes the complaints known as fistulous withers and poll evil.

The species which bite man, however, can be exceedingly unpleasant. The irritation caused by the bites may persist for days or even weeks. It has been stated that the irritation is allayed if the bite is moistened and rubbed with a crystal of sodium carbonate, even up to a day after the actual puncture.

Scratching aggravates the pruritus and may lead to bacterial infection and slow-healing sores. A common result is a moist open lesion that 'weeps' serous exudate for weeks, finally healing with a definite red scar.

There are about 150 species of Ceratopogonidae in Britain but a large proportion of them are harmless, since they are predaceous on other insects or are vegetarian. The troublesome members are about half a dozen species of *Culicoides*, by far the most important being *C. impunctatus*. Other annoying species are *C. obsoletus*, *C. pallidicornis*, *C. pulicaris* and *C. heliophilus*. They are common in rough open country such as heather moors, bracken-covered hillsides and clearings in woods, especially in the north and west of Britain. *Culicoides vexans* is troublesome in the south of England; but, generally speaking, biting midges are most serious in Scotland. During July and August it occurs in very large numbers which may actually prevent outdoor work, and it has been suggested that the backward condition of croft farming in western Scotland may be due to the pernicious activities of this midge. (Analogous suggestions have been made about related midges on the Southern Atlantic seaboard of the U.S.A.) The attacks of midges certainly deter tourists from staying in certain fishing, walking and climbing resorts. In 1945 the Scientific Committee of the Scottish Department of Health was sufficiently concerned about the problem to set up a special sub-committee to investigate the possibilities of alleviating the nuisance.

#### (e) Control<sup>(15, 20, 21)</sup>

In recent years considerable progress has been made towards the possibility of controlling *Culicoides* by larvicidal treatments. One of the most hopeful findings was that the most annoying species, *C. impunctatus*, is restricted in its choice of breeding grounds to wet areas of moorland beset with typical vegetation; an association of the jointed rush (*Juncus articulatus*) and bogmoss (*Sphagnum* sp.). In addition, field observations strongly suggested that the adults were unlikely to fly more than a few hundred yards from the breeding sites.

Trial insecticidal treatments have shown that DDT at 5 lb/acre or dieldrin at

1 lb/acre, applied as suspensions or emulsions, can give good and persistent control. In some cases, time and a period of rainy weather, are necessary to wash the insecticides well into the soil.

While these initial experiments have been promising, large-scale application raises difficulties. For one thing, vehicles (e.g. Land Rovers) used to apply large quantities tend to get stuck in the boggy breeding sites. Another setback was that breeding sites over a wide area may need treatment as the flight range may perhaps be farther than originally supposed.

Against adult midges, it is only feasible to employ defensive measures. Screening is difficult owing to the small size of the flies; veils with a mesh small enough to exclude the midges are too hot to work in and obscure the vision. Some success has, however, been reported with relatively wide mesh veils impregnated with repellents (see p. 113).

For personal protection, the repellent dimethyl phthalate has been found very satisfactory. An ointment which contains at least 40% 'DMP' will give complete protection from bites on the treated areas for nearly three hours.<sup>34</sup>

## V · BLACKFLIES (Simuliidae)

### (a) **Distinctive characters** (Fig. 20a)

Blackflies can be fairly easily recognized from their general appearance. They are small, hump-backed black flies with clear, broad wings, of which the anterior veins are considerably thicker than the remainder. They vary from about 2 to 6 mm in length and are thus, on the average, smaller than mosquitoes but larger than midges. The body is stouter and the legs relatively shorter than those of midges and mosquitoes. The antennae, though many-jointed, are quite short and bare in both sexes.

### (b) **Life history**<sup>(32, 38, 44)</sup>

#### (i) *Oviposition*

Blackflies breed exclusively in fresh rather rapidly flowing streams. The females lay their eggs on the leaves of aquatic plants, on twigs or plants dipping into the water and on submerged stones, in some cases entering the water to do so. The eggs are deposited in large masses sometimes enveloped in a gelatinous matrix.

#### (ii) *Egg*

The eggs have a rounded triangular cushion shape. White when newly laid, they become brown in a few hours and darken still further towards the end of incubation.

#### (iii) *Larva*

The larvae are very characteristic. There is a well-developed head with pigmented eye spots and small antennae. There are two appendages above the mouth, each bearing a fan-like spray of bristles. These are apparently specialized parts of the labium and their purpose, like the mouth brushes of mosquito larvae, is to gather small particles of food. When not being used the bristles close up like a fan.

The rest of the body is shaped somewhat like a truncheon, the thorax being the handle. There is a proleg on the thorax and a misnamed posterior 'sucker' at the end of the abdomen; both are furnished with tiny hooks and are used in locomotion. The larvae spin silken threads over submerged leaves and stones and progress with a looping motion, using these two prolegs. Sometimes they let go and hang downstream on a silken thread, in which case they either climb back up it or drift down to a new site.

Respiration is carried out through finger-like gills extruded through the anus. The larvae are rather sensitive to oxygen lack and can only survive in well-aerated flowing water. There are apparently six larval stages.

#### (iv) *Pupa*

Before pupation the larva spins a slipper-shaped cocoon with the 'toe' pointing upstream. The pupa is roughly conical and immobile. From the thorax on each side arises a short stalk bearing a group of respiratory filaments, about as long as the pupa itself. When the adult fly is fully formed, air is collected within the pupal skin; finally the skin splits and the fly escapes and floats up to the surface in a bubble of air.

#### (v) *Adult*

The mouthparts of the adult are even shorter and broader than those of *Culicoides* but they are similar in arrangement, and the method of biting is the same (see p. 207 and Fig. 22c). The general appearance of the adult fly has already been briefly described.

Unlike midges, blackflies have a very considerable range of flight. Swarms originating at a notorious breeding place on the Danube, near the Iron Gate, may spread over the surrounding countryside to a distance of 50 miles or more.<sup>(4)</sup>

The biting activities of the adults seem to be most intense when the air humidity is high and there is little wind. The species troublesome in Britain frequently bite horses and cattle on the inner sides of the thighs, the belly, the nose and sometimes the ears.

### (c) Quantitative bionomics

The females lay up to several hundreds of eggs. The eggs of the Scotch species *S. ornatum* hatch in 5–6 days at 16°C (60°F). Larval life occupies about 7–10 weeks at this temperature and the pupal period about a week. The complete life cycle may extend to nearly 3 months in the summer and considerably longer over the winter months owing to a greatly extended larval period (up to 6 or 7 months).

In Britain most species have two and sometimes three generations per year, the spring brood being sometimes different in size and morphology from the summer one.

### (d) Importance

Over large parts of the tropics, blackflies are vectors of the parasitic worm *Onchocerca*, which causes nodules, tumours and skin eruptions and can lead to blindness.

In addition, blackflies may occur in many countries in vast numbers and the effects of numerous bites may be serious for livestock as well as man.

In Britain, the attacks of blackflies are much less serious, but the following species can be troublesome to man: *S. erythrocephalum* in the Midlands and eastern counties of England and the lowlands of Scotland; *S. reptans* throughout Britain but mainly in the north and west; *S. ornatum* but mainly in the south. These species and others, such as *S. equinum*, will also bite cattle and domestic animals.

### (e) Control

Abroad, where *Simulium* may be a disease vector, serious attempts have been made to eradicate it completely from the streams in considerable areas. Very encouraging results have been obtained by introducing DDT into the water upstream.<sup>(9, 41)</sup>

In Britain it is doubtful whether the pest is serious enough to warrant extensive control measures. Personal protection in affected areas can be obtained by the use of repellents as described for *Culicoides* (see p. 209).

## VI · HORSEFLIES (Tabanidae)

### (a) Distinctive characters

The Tabanidae are quite unlike any of the biting flies considered so far. They are rather large, robustly built flies, resembling more a housefly or a bluebottle than any fragile gnat or midge. The biting mouthparts of the females, however, retain the primitive piercing labrum, mandibles and maxillae which are entirely lacking in the more specialized flies. The younger stages, too, are intermediate in specialization; the larva has a head (though much reduced) and the pupa, like more primitive flies, is not formed in a barrel-shaped puparium like the housefly and its relatives.

### (b) Life history<sup>(29)</sup>

#### (i) Oviposition

The larvae are aquatic or semi-aquatic (damp soil) and the females oviposit on the leaves of plants or on rocks etc. in water or swamp ground.

#### (ii) Egg

The eggs are spindle-shaped and about  $1\frac{1}{2}$  mm long. They are laid in neat clusters consisting of one or two layers stacked vertically. On being laid they are white, but they darken to greyish brown in a few hours.

The egg clusters of British Tabanidae are difficult to find in nature, but the females will often lay readily in captivity.

#### (iii) Larva

The larva is a legless grub with a small retractable head and a cigar-shaped body with eleven segments. Each of the first seven abdominal segments bears a ring of eight 'pseudopods' or fleshy processes, presumably concerned with locomotion. The skin is creased with fine longitudinal striations, and is sometimes marked with dark bands. At the posterior end, there is sometimes a short tubular 'siphon' at the

end of which are a pair of spiracles which lead to the two longitudinal tracheal air trunks running along inside the body.

Upon hatching, the larvae usually drop into water and bury themselves in mud at the bottom. They spend the rest of their larval life in wet mud or shallow water.

There are three to eight larval stages, the first of which is gregarious and takes no food but subsists on yolk acquired in the eggs. The older stages are carnivorous (except for species of *Chrysops*) and prey on small crustacea, worms, snails and insect larvae. If kept in captivity they often become cannibalistic.

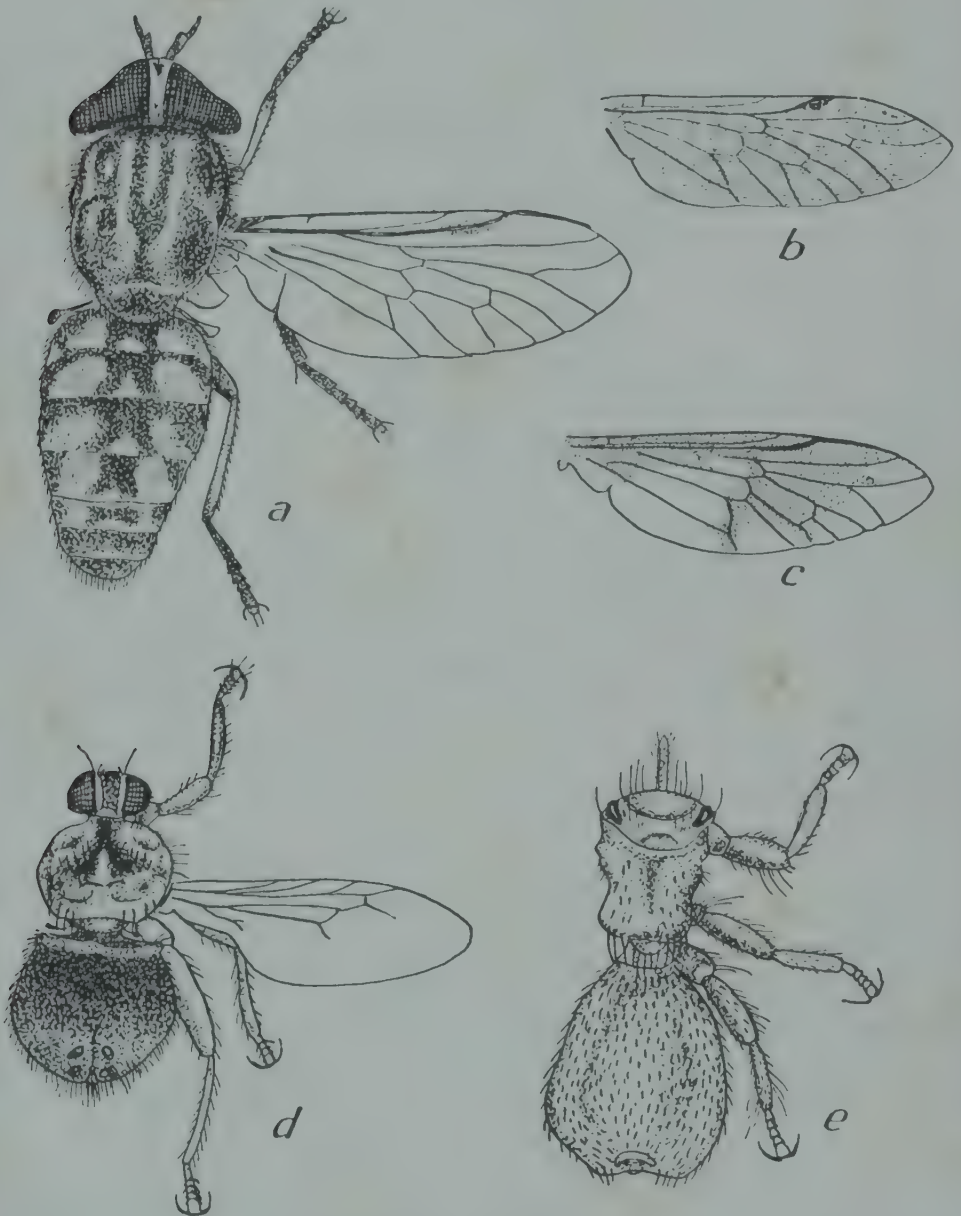


FIG. 21. Biting flies. (a) *Tabanus bromius* (female); (b) wing of *Haematopota pluvialis*; (c) wing of *Chrysops sepulcralis*; (d) *Hippobosca equina* (female); (e) *Melophagus ovinus* (female). (After Edwards, Oldroyd and Smart, l.c.) (a)  $\times 3\frac{1}{2}$ ; (d)  $\times 4$ ; (e)  $\times 7$ .

*(iv) Pupa*

Pupation occurs in earth or mud round the margins of ponds. The fused head and thorax of the pupa displays the rudiments of the adult appendages. The abdominal segments bear rings of short bristles and the tip of the abdomen carries a cluster of six large tooth-like spines. The adult finally emerges through a longitudinal split in the back of the pupal skin.

*(v) Adult (Fig. 21a, b, c)*

The adults are rather handsome flies with large eyes which are often iridescent in life, with beautiful gold, green and blue tints. The species of two of the three British genera have mottled or dappled wings thus:

*Chrysops* has wings with a conspicuous brown or black cross-band.

*Haematopota* has wings mottled with grey.

*Tabanus* has clear wings, but sometimes with a brownish tinge towards the fore border.

The antennae of tabanids are rather well developed, for the group (Brachycera) to which they belong, and are carried projecting from the front of the head.

The mouthparts contain the same piercing elements as in the gnats and midges; that is, piercing labrum (overlip), mandibles and maxillae. There are rather short palps, shaped like pointed clubs, and an elastic labium which is curved back when the piercing stylets are thrust into the skin (Fig. 22e).

The labium bears a pair of licking lobes or 'labella' covered with fluid-absorbing grooves like that of the housefly. This is used by both sexes for drinking water and possibly plant juices.

The females apparently do not take blood meals unless they are fertilized. In Britain *Haematopota pluvialis* is the commonest species and may be quite common near its breeding grounds in low-lying marshy country. The flies approach silently and rapidly and frequently bite about waist-high, on the wrists, for example. Species of *Chrysops* generally give more warning by flying round the head with a high-pitched hum; they often bite at the back of the neck. The various *Tabanus* spp. seem generally to prefer to bite on the legs; *T. bromius* (Fig. 21a) is the commonest.

**(c) Quantitative bionomics**

The females lay batches of several hundreds of eggs. These hatch in from four to twelve days according to the temperature. The larval stage is somewhat prolonged and in temperate climates the fly passes the winter in this form; sometimes, indeed, two winters may be passed before development is completed. Pupation occupies about 1 to 3 weeks. As a rule most British species have not more than one generation per year.

**(d) Importance**

Tabanidae are not specifically incriminated with the normal transmission of any particular disease, though they are sometimes responsible in tropical countries for transmitting parasitic worms and various pathogenic organisms.

All the females are liable to suck the blood of man or domestic animals, however, and the wounds inflicted are rather painful and may give rise to considerable irritation. The delayed reaction of the bite varies greatly in different people. In Britain, it is fortunately rare that they ever occur in large numbers; they are localized in distribution and only bite out of doors in country districts.

In early records there was a mistaken belief that Tabanidae are responsible for

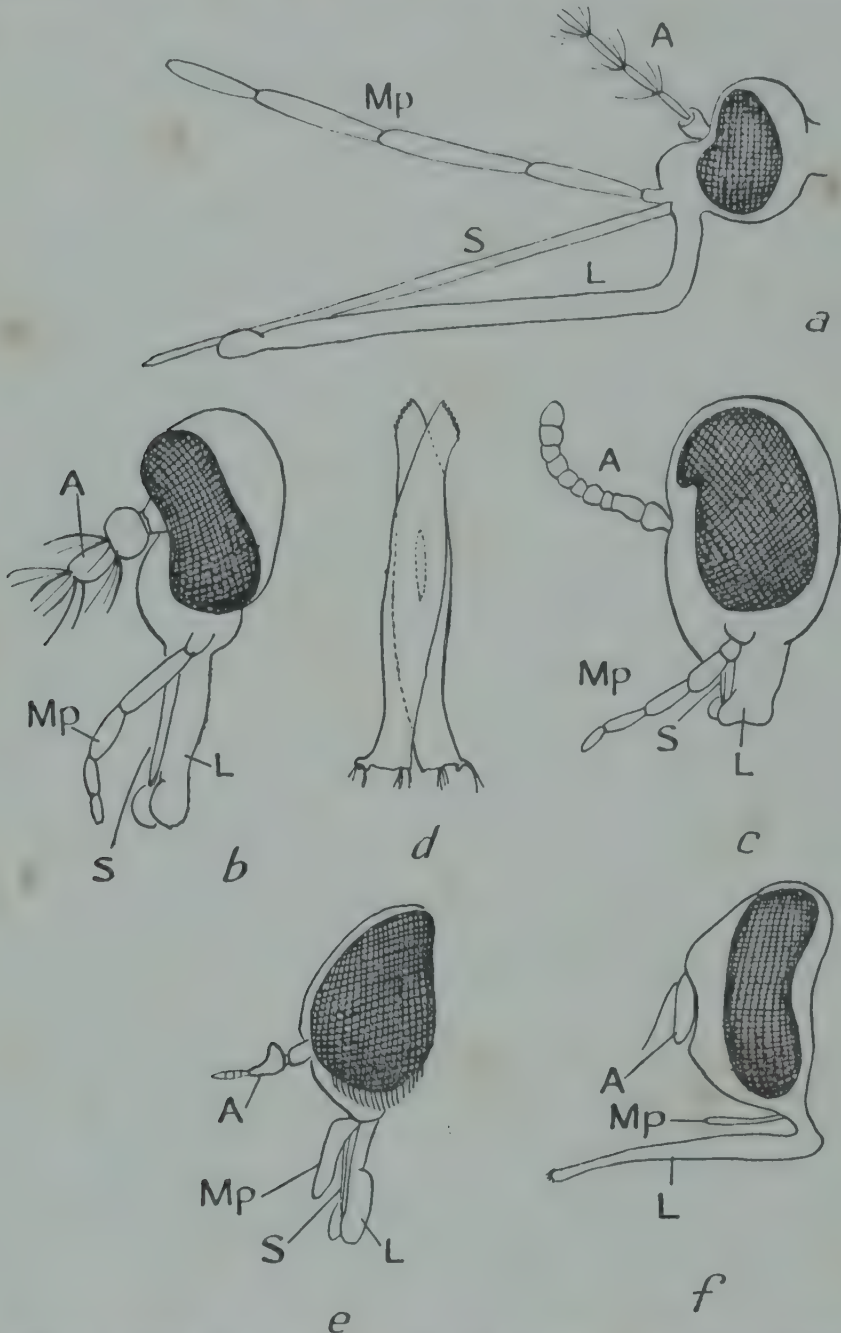


FIG. 22. Heads of biting flies, all viewed from the left side. (a) *Anopheline* mosquito (with labium partly retracted, as in biting); (b) *Culicoides*; (c) *Simulium*; (d) mandibles of *Simulium* further enlarged and viewed from above to show scissor-like action; (e) *Tabanus*; (f) *Stomoxys*. In all cases: A, antenna; Mp, maxillary palp; S, stylets (mandibles and maxillae); L, Labium. (After various authors.)

the phenomenon known as 'gadding' in horse and cattle. (This is apparently sometimes due to the presence of 'bot' flies; see p. 5.) The repeated bites of horseflies or clegs may, however, cause a good deal of restlessness among cattle, which may be detrimental. In countries where they are numerous, they may cause the loss of about half a pint of blood per day.

### (e) Control

In Britain, horseflies are rarely sufficiently numerous to demand control measures, which are difficult to institute. Some reduction may be obtained by draining off suitable breeding grounds and by oiling the surface of ponds from which adults may be observed to drink. Cattle may be given some relief by the provision of sheds in which they can shelter, since these sun-loving flies do not like to enter such places.

Persistent attacks on human beings may perhaps be prevented by the use of a repellent such as dimethyl phthalate.

## VII · THE STABLE FLY (*Stomoxys calcitrans*)

Nearly all the more highly developed flies such as the housefly and its relatives have specialized mouthparts in the adult stage which are adapted to licking up exposed fluids. The parts used by gnats and horseflies for piercing skin are completely atrophied. Nevertheless, a few members of the Muscidae have developed the blood-sucking habit (possibly via the habit of drinking blood from small wounds; see p. 185). These species pierce the skin with the labium which is modified into a horny beak instead of being a soft proboscis. This horny, beak-like proboscis is carried horizontally and projects in front of the head, providing a ready means of distinguishing these flies from the non-bloodsucking muscids. The modified proboscis and the bloodsucking habit occurs in both sexes.

Three flies of this type occur in Britain, all rather similar to the housefly in general body form. They may be distinguished as follows:

- A. Proboscis long, projecting a head's length in front, palps short, and thread-like  
*Stomoxys calcitrans*.
- B. Proboscis shorter, palps club-shaped and shorter than proboscis  
*Siphona stimulans*.
- C. Proboscis short, palps not club-shaped and as long as proboscis  
*Siphona irritans*.

The African tsetse flies (species of *Glossina*) belong to the same group.

Flies of the genus *Siphona* accompany cattle in the fields and bite them from time to time. *S. irritans* is known as the 'horn fly' from its habit of resting at the base of the horns. It is the more completely adapted to a parasitic life on the cattle, which it only leaves voluntarily for short periods, to lay eggs, etc. It rarely bites man. *S. stimulans* is less specialized; it leaves the cattle more readily and does not rest on them at night. Also it is prone to bite man; for example, the legs of people milking cows.<sup>(12)</sup>

Both species of *Siphona* breed in cattle droppings in the fields and pupate in the earth beneath. One method of control is to break up and scatter cow pats with harrows or branches, so that the dung dries up and the larvae die.

### (a) **Distinctive characters**

This fly is very similar in general appearance to the common housefly and, since it is sometimes encountered indoors, it has been called the biting housefly. As already mentioned, the proboscis projecting in front of the head, which is even visible from above, enables it to be easily distinguished from the common housefly. The fourth wing vein also does not bend sharply, as in *M. domestica* (Fig. 14h).

### (b) **Life history**<sup>(31)</sup>

#### (i) *Oviposition*

The females lay eggs in horse, pig or calf manure, in decaying straw or in various types of rotting vegetation. They breed very well in the bedding of farm animals, especially if it is soiled by dung or urine. Under hot conditions (27°C) the females mate when 6 days old and lay eggs 1 or 2 days later. About 10 batches of some 35 eggs may be laid over a period of 12 days. In cooler conditions, the oviposition period is more extended and the batches may contain about 100 eggs.

#### (ii) *Egg*

The eggs are about 1.1 mm long and 0.2 to 0.3 mm thick, narrowly oval and slightly pointed at one end.

#### (iii) *Larva and pupa*

The larvae resemble those of the housefly in general appearance and habits. After the usual three stages, reaching a length of some 11 mm, they pupate in the same way, usually leaving the breeding material for a drier zone. Larval and pupal development periods are greatly extended at low temperatures and probably represent the usual method of passing the winter.

#### (iv) *Adult*<sup>(42)</sup>

After emergence, the adults expand their wings, and the proboscis, which is folded backward in the pupa, extends forward and hardens. The flies are able to feed a few hours after emergence. Both sexes take blood regularly and, while they will also take sugar solution, they thrive best and survive longest on blood meals. Though cattle are apparently the preferred source of blood, *Stomoxys* will also feed on many different animals, including horses, pigs, dogs and men. Like cattle, men are often bitten on the legs, socks or stockings being no protection. In feeding, the proboscis is directed downwards and the fly rasps a way through the skin by everting the small labella at the tip; this exposes the file-like teeth on their inner surfaces (Fig. 22f). Often several tentative incisions are made before a good blood supply is discovered. Undisturbed feeding takes about 15 minutes, but the flies are often brushed away

by the victim and return to make another attempt. The weight of a full meal (about 25 mgm) is roughly three times that of the fly.

Stable flies feed only in daylight and the need for meals increases with temperature. In hot weather ( $25^{\circ}\text{C}$ ,  $77^{\circ}\text{F}$ ) the blood is digested in 12 to 24 hours and meals are taken every 1 to 3 days.<sup>(11)</sup> In cool weather digestion may require 2 to 4 days and feeding may be delayed for 10 days. Below  $9^{\circ}\text{C}$  ( $48^{\circ}\text{F}$ ) the flies make no effort to find food and remain quiescent. Although the need for food is less, the final result of prolonged low temperature is starvation. Accordingly adult flies seldom survive the winter in unheated buildings, though in warm stables and cowsheds, intermittent feeding may continue until the following spring.

The habits and behaviour of stable flies differ in several ways from those of houseflies.<sup>(42)</sup> They are rural in distribution, being virtually absent from large towns. In warm weather they may be encountered in the open and they are common in stables and cattle sheds; less frequently, they enter houses. They spend more time resting than houseflies, possibly because they do not need to quest so much for food. After a meal many of them rest in animal houses, usually choosing the darkest places, high up on the walls or ceiling. Nearly always, they rest with the head upwards and the body inclined at an angle to the surface. (In contrast, houseflies often rest head down, in a crouching position with the body parallel to the surface.) Activity begins with daylight when stable flies tend to explore the lower parts of the animal houses and seek the cattle. Most of their flights are quite short (less than 1 m) and are mainly concerned with seeking food or mates.

Mating, like that of *M. domestica*, originates with visual stimuli and male stable flies often attempt to mate with each other or even jump on to small dark objects.

Over the temperature range, activity begins at  $10^{\circ}\text{C}$  ( $50^{\circ}\text{F}$ ), is maximum at  $28^{\circ}\text{C}$  ( $82^{\circ}\text{F}$ ) and heat paralysis sets in at  $42.6^{\circ}\text{C}$  ( $108^{\circ}\text{F}$ ). The range is thus somewhat narrower than that of *M. domestica* (see p. 168).

#### (c) Quantitative bionomics<sup>(22)</sup>

At  $16^{\circ}\text{C}$  ( $60^{\circ}\text{F}$ ) E 5; L 34; P 19.

At  $20^{\circ}\text{C}$  ( $68^{\circ}\text{F}$ ) E 2; L 16; P 14.

At  $25^{\circ}\text{C}$  ( $77^{\circ}\text{F}$ ) E 1.5; L 9.5; P 6.5.

At  $30^{\circ}\text{C}$  ( $86^{\circ}\text{F}$ ) E 1; L 6; P 5.

Minimum development times therefore range from 7 weeks at  $16^{\circ}\text{C}$  to 12 days at  $30^{\circ}\text{C}$ , in all cases being slower than *M. domestica*.

Normal adult life is unknown but flies have been kept alive for 10 weeks in the laboratory.<sup>(28)</sup>

#### (d) Importance

The stable fly has been accused, especially in the U.S.A., of taking part in the transmission of poliomyelitis; but the evidence is very tenuous.

When they are numerous, stable flies are very objectionable from their biting habits, not only in the open but in cool weather when they may enter houses. Dairy farmers find that their bites may irritate cows sufficiently to reduce milk yield.

## (e) Control

To prevent breeding, the sides of hay and straw stacks should be kept vertical and the tops rounded and thatched so that the rain drains off. Loose straw and chaff should be burnt or scattered; the important thing is to prevent accumulation during the summer months of rotting straw, chaff or other vegetation in a damp (or especially a urine-soaked) condition.<sup>(2)</sup>

Larvicidal treatments suffer from the same drawback as in housefly control, viz. the bulk of material to be treated in order to reach the larvae. However, a 1 : 3 creosote-water emulsion applied at the rate of 1 gal/85 sq ft was effective in controlling breeding in decaying marine grass deposits in U.S.A.<sup>(37)</sup> Less troublesome is the application of contact insecticides on or near the breeding grounds, to kill emerging adults. A 0.5% DDT emulsion applied at 1 gal per 240 sq ft on the above-mentioned marine grass was effective in this way.<sup>(13)</sup> In Uganda, 4% chlordane applied to vegetation near cattle pens killed adults in the same way.<sup>(30)</sup>

Treatment of cattle sheds and milking sheds with a residual DDT spray has been found to be of some value in reducing numbers of *Stomoxys* and other flies, with the result that the cattle are less restless and give better milk yields. A residual treatment more rapid in effect than DDT-kerosene spray seems to be required. In Norwegian cattle sheds, trichlorophon has been used satisfactorily; but it is not effective on lime-washed or cement walls.<sup>(39)</sup>

It should be noted that resistance to chlorinated insecticides has been developed by laboratory selection of *S. calcitrans*; and though it does not seem to have arisen in the field, the threat is obviously present.<sup>(40)</sup>

In the fields, the animals may be protected by application of repellent sprays containing pine oil derivatives.

## VIII · PUIPIPARA

These flies are a remarkable group, apparently related to flies of the muscid type, but highly specialized and often degenerate. They are all parasitic on birds or mammals and live among the fur or feathers, sucking blood at intervals. They are specific parasites of various wild and domesticated animals and rarely or never bite man.

Their bodies are flattened and leathery and the feet bear strong claws for gripping the host. The powers of flight are reduced and sometimes the wings are vestigial or absent. The mouthparts contain the same elements as the biting muscids.

The Hippoboscidae include the species *Melophagus ovinus*, the 'sheep ked', which is of some economic importance. This is a curious, deformed-looking wingless insect which crawls among the fleece like a kind of spider (Fig. 21e). Heavy infestations cause considerable irritation to the sheep which then rub themselves and may cause abrasions inviting the attentions of the sheep blowfly, *Lucilia sericata* (see p. 180). Like all Hippoboscidae, *Melophagus* is larviparous and gives birth to large larvae; these pupate at once and remain in the fleece. The whole life history is thus passed on the host animal.

*Hippobosca equina*, the 'forest fly', occurs on cattle and ponies in the New Forest

region (Fig. 21d). The Nycteribidae and the Streblidae are parasitic on bats, the latter family being confined to the tropics and warmer regions of the world.

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## 10 · *Parasites*

The pests to be considered in this chapter comprise several quite different types of insects as well as mites and ticks. They are all parasitic on man and are grouped together because this habit causes them to be of medical and hygienic significance. They will be arranged, primarily, according to the type of control measures they require, which depends on the closeness of their association with the host. Pests such as the itch mite, the crab louse and head louse live in continual proximity to the skin and require personal disinfestation to destroy them. On the other hand, fleas and bed bugs, which visit the host only at intervals, demand the disinfestation of furniture and buildings. A compromise will be attempted between this empirical arrangement according to methods of control and certain other considerations such as the relative importance and systematic relationships of the pests concerned.

### *A · Parasitic insects*

#### THE BED BUG (*Cimex lectularius*)

##### (a) **Historical notes**

The bed bug probably originated as a parasite in a semi-tropical region, possibly in the Middle East. The more northerly countries of Europe were not invaded until comparatively recent times (Germany in the eleventh century, England in the sixteenth century, Sweden as late as early nineteenth century).

On the other hand, the Mediterranean region was infested in ancient times. Aristotle is recorded as having considered that bed bugs are generated from sweat and also from other humours that sweat out of wood. Bacchus, on descending to Hell, is said by a Greek tragedian, to have requested Jupiter to assign to him such inns on the journey where there were but few bugs.

The Romans referred to the bugs as *Cimex*, which word was afterwards fixed as the generic name by Linnaeus. Pliny and Quintus Serenus refer to it as a medicine. The bugs were taken either crushed or whole in water or wine. The diseases and failings which bugs were expected to alleviate were very various and comprehensive. They include snake-bite, strangulation, Quartian ague, lethargy and the stone. Some of these remedies were given in an old *materia medica* by Dioscorides (text of 1516).

The earliest discovered account of bed bugs in English is that given by Mouffet, an English translation of whose *Insectorum sive minimorum animalum theatrum*, was published in 1658 together with Edward Topsel's *History of four-footed beasts*. Mouffet gives Greek, Latin, Arabian, Saxon, German, Brabant, Spanish, Italian and French synonyms as well as the English term then used, namely 'wall-louse'.

The large number of synonyms indicates that the insect was widely known in Europe at that date, though it does not seem to have been common in England – certainly not inland. Mouffet mentions an incident recorded in Mortlake on Thames in 1583. The incident in question concerns two noblemen who were much alarmed by the marks of bug bites and had to be ‘laughed out of all fear’ by their physician.

The name bug, which is now associated with *Cimex* and, more generally, with others of the order Hemiptera, is of uncertain origin. It is sometimes stated to be derived from the old word ‘bug’ meaning a terror or hobgoblin (cf. bugaboo, bogy); but there is no good evidence for this (O.E.D.).

### (b) Distinctive characters

The bed bug *Cimex lectularius* is a quite anomalous member of the order Hemiptera. There is considerable variation in form among the members of this large group, which includes the big tropical cicadas, the ubiquitous aphids, the scale insects, the leaf hoppers and aquatic forms like the ‘water boatman’. All of them, however, have in common the piercing and sucking type of mouthparts, and the vast majority are vegetarian and use these mouthparts to suck out the sap of plants.

Many bugs are serious agricultural pests. A small proportion of species attack other insects and suck out their vital juices and an even smaller number have adopted the very specialized habit of living on blood sucked from birds and mammals. (This habit, as we have seen, developed at least twice in the evolution of the Diptera.)

There are several families of Hemiptera which include bloodsucking members; the most important being the Cimicidae, to which the bed bug belongs, and the Reduviidae, which includes certain tropical forms not found in Britain (‘cone noses’, ‘kissing bugs’ and ‘assassin bugs’). The Cimicidae includes two species of *Cimex*: *C. lectularius*, the common bed bug, and *C. hemipterus*, the tropical bed bug. The latter is somewhat less efficient in its adaptation to environment, especially in cooler climates; so that whereas *hemipterus* is not likely to spread into temperate climates, *lectularius* is common in many regions all over the world. Certain other Cimicidae are parasites of bats and such birds as swallows and martins. This seems to suggest that *Cimex* became adapted to man during a cave-dwelling period of his prehistoric past.

The adult bed bug, *C. lectularius*, is a flat, oval insect about 6 mm long. As with other insects displaying only partial metamorphosis, the nymphal stages resemble the adult. The similarity is augmented by the fact that the adult is virtually wingless, except for a pair of small oval scales, representing vestiges of the forewings (Fig. 23).

### (c) Life history<sup>(29)</sup>

#### (i) Oviposition

Bed bugs live away from their host in crevices in the furniture or walls of rooms in which people sleep. It is in these harbourages that the eggs are laid, often in considerable numbers. As the female deposits them, they are covered with a thin layer

of quick drying glue which cements them to the surface on which they are laid. This glue fastens the egg down permanently, so that the empty shell remains fixed in position long after hatching.

(ii) *Egg*

In shape, the egg is somewhat like a rubber teat, the open end being covered by an egg-cap. In size it varies from 0.8 to 1.3 mm long and 0.4 to 0.6 mm broad. At a certain point in incubation, the eyes of the young insect are visible through the shell as two pink spots. Hatching is accomplished by the insect breaking off the egg-cap which usually falls off like a manhole cover.

Unhatched eggs are pearly and opaque, whereas, after hatching, the empty egg shells are opalescent and translucent.

(iii) *Nymph*

The habits of nymphal bed bugs resemble those of the adults. During the day they remain hidden in cracks and crevices, which is facilitated by their flattened shape. At night they may emerge, and from time to time they seek and find a sleeping person (or animal) from which to take a blood meal.

There are five nymphal stages, all of them approximately resembling the adult in shape. The cuticle of the abdomen of nymphs is relatively thinner, however, and displays the colour of the partly digested blood inside; whereas the adult cuticle is stiffer and a mahogany brown in colour. All stages, including the adult, are white to pale straw colour immediately after moulting (or after hatching) but the harder parts of the cuticle darken to an amber or mahogany colour in a few hours.

The sizes of all stages of bugs vary considerably, not only because of individual variation but because of the great expansion of the abdomen after each meal. (The quantity of blood taken at a meal may be from  $2\frac{1}{2}$  to 6 times the bug's original weight.) The approximate sizes of the various nymphal stages, before feeding, are as follows: <sup>(20)</sup> Stage I 1.3 mm, II 2.0 mm, III 3.0 mm, IV 3.7 mm, V 5.0 mm. Each nymphal stage requires one full meal of blood before it proceeds to the next moult. The feeding and many other habits of the nymphs are substantially the same as in the adult stage and will be considered in the next section.

(iv) *Adult* (Fig. 23)

The head of the bug bears two fairly well-developed antennae and a pair of rather inefficient compound eyes (containing about 30 facets, mostly on the dorsal side). The mouthparts, like those of most Hemiptera, consist of stylet-like mandibles and maxillae resting on a groove on the top of a three-jointed labium; the upper lip or labrum overlaps the beginning of this 'proboscis'. Normally the proboscis is carried bent backwards under the head, but it is extended forward when the bug prepares to feed. Comparatively little is known about the stimuli which cause bugs to seek and find the host under natural conditions. There is no experimental evidence to show that a bug can perceive a source of food at a greater distance than 2 or 3 inches. At close range, warmth seems to be the predominant stimulus; a hungry bug will follow and attempt to probe a test-tube of warm water. It may be that they

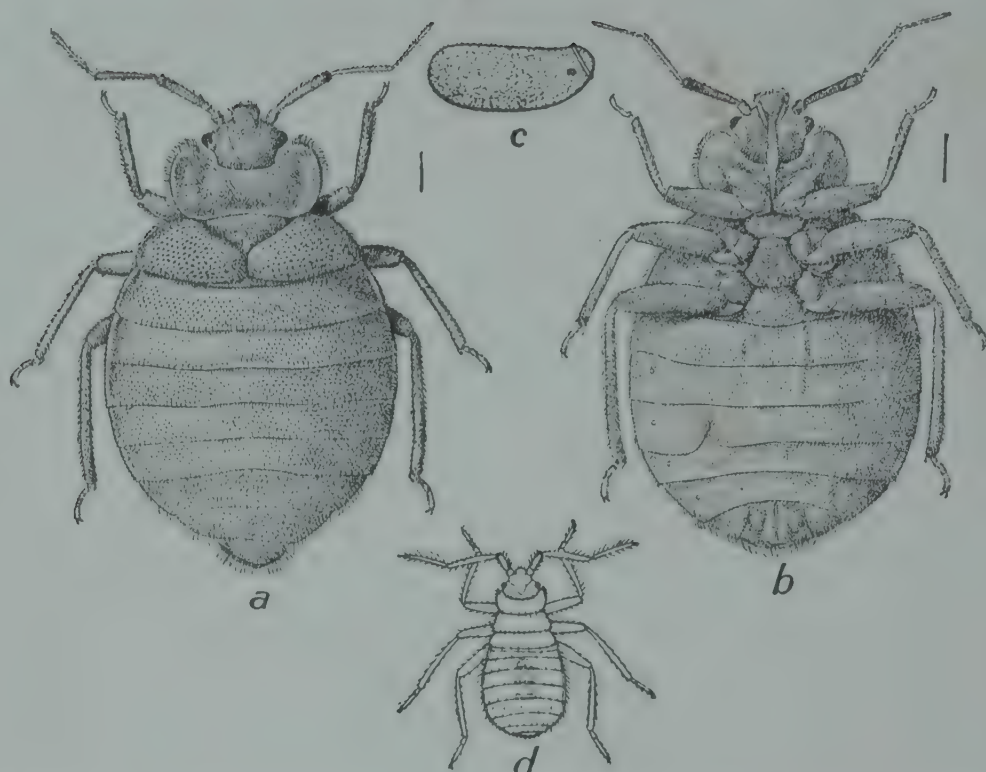


FIG. 23. *Cimex lectularius* (the bed bug). (a) adult male (dorsal view); (b) adult female (ventral view); (c) egg; (d) first-stage nymph. From McKenny-Hughes and Johnson (1942) Brit. Mus. (Nat. Hist.) Econ. Series No. 5. (a) & (b)  $\times 10$ ; (c) & (d)  $\times 15$ .

get into close proximity by frequent random wandering.<sup>(52, 53, 54)</sup> Most bugs are found in the bed frame or wall close to the sleeping host, though it is true that some may be found in quite distant parts of the room.

During feeding, the stylets pierce the skin while the labium curves away from them, retaining contact at skin level, as in a biting mosquito. The external stylets (mandibles) are very slender needle-like structures which serve to pierce and lacerate the wound and each has a row of about twenty teeth near the tip. The inner pair of stylets (maxillae) are much stouter and longer; they are grooved on the inner side and, just in front of the mouth, they are locked together to form two canals, dorsal and ventral. The broader dorsal channel is the food tube up which the blood is drawn by the action of a pharyngeal pump in the head. The lower canal, which is much narrower, conducts saliva into the wound. The saliva is secreted by glands in the thorax which discharge into a tiny pumping chamber which in turn injects the juice into the base of the saliva canal.

As a rule, the bug takes about 5–10 minutes to suck a full meal of blood. Occasionally this may be prolonged if it has chosen a site from which it is difficult to draw blood. Old adult bugs take longer than younger ones to feed and very senile ones are sometimes incapable of it, though they can pierce the skin with their mouthparts.

The gut of the bug consists of a narrow tube, running back to the abdomen, where it expands into a large sack-like crop, followed by a coiled midgut and a short rectum. As usual, Malpighian tubes discharge into the front end of the hindgut.

The bug's intestines usually appear to be a dull purple colour owing to partly digested blood inside. The faeces vary from a dark brown or black, viscous liquid to pale straw-coloured matter. The faecal deposits result in the characteristic speckled appearance shown by bug-infested walls, especially in the neighbourhood of harbourages.

Some further points of external anatomy await consideration. The first segment of the thorax is prominent; it bears on each side a characteristic leaf-like expansion which curves forward nearly as far as the eye. The legs are well developed but normal. The feet bear claws which can grasp quite minute irregularities and thereby climb up a vertical surface such as paper or wood. They cannot climb *clean* glass or polished metal, but a slight film of dirt or corrosion gives them sufficient foothold to climb slowly. They can walk upside down on rough paper and similar surfaces, but are not very secure and sometimes fall off. Bugs appear to run quite fast and, at least with forceps, are difficult to catch; actually their average speeds are quite low (newly hatched bugs travel about 8 inches per minute and adults about five times as fast (i.e. 1/100th and 1/25th mph)).<sup>(20)</sup>

The greater part of a bug's life is spent in a state of immobility, usually in corners or cracks about a room, or in furniture. They avoid light and are most likely to emerge from their harbourages at night. A light left burning all night will discourage activity but not prevent it; moreover the period of maximum activity is not soon after dark but shortly before dawn. There seems to be some unknown rhythmic factor which induces activity.<sup>(35)</sup> In cool weather bugs may remain in the same crevices without emerging for as much as a month at a time.

The abdomen of the bug has an almond-shaped outline, the tip being more pointed in the male and more rounded in the female. The thickness varies enormously according to the time elapsing since the last meal; the inflated thickness immediately after feeding alters slowly to a wafer-like form after protracted starvation. The abdomen also extends in length (telescopically) after feeding, to accommodate the bulky blood meal.

When they are disturbed, bed bugs emit a characteristic odour due to the secretion of so-called 'stink glands'. These lie on the back of the abdomen in nymphs but are replaced by a large gland under the thorax in the adult. It is sometimes claimed that bug-infested houses can be recognized by the smell, but in the writer's experience, most badly infested houses emit a disgusting mixture of odours characteristic of lack of hygiene. The smell emitted by bugs in a test-tube is not particularly unpleasant.

The genital organs and mode of fertilization are unusual. The male has a sickle-shaped intromittant organ curving round the tip of the abdomen pointing to the left. This 'penis' is not introduced into the egg pore of the female but into a curious organ with an opening underneath the abdomen on the right. In copulation, which does not last long, the male mounts the female and curls his abdomen over the right side of hers and inserts the penis into the copulatory pore. This leads into a bag-like organ and the sperms inserted bore their way through the walls of the bag and migrate through the body cavity to the oviducts. They enter these and fertilize the eggs as usual. The eggs pass normally down the oviducts to the egg pore.<sup>(16)</sup>

(d) Quantitative bionomics<sup>(26)</sup>

The development and proliferation of bed bugs are mainly dependent upon the prevailing temperature and the available food supply. The two factors are inter-dependent, since the need for food is regulated by the temperature. Nearly all our knowledge on this subject relates to artificial laboratory conditions in which the bugs were reared at various constant temperatures and offered a meal at different intervals by being placed close to a host.

In nature, bugs are exposed to fluctuating temperatures and are compelled to find their own way to the host before they can feed. It is probable that the constant laboratory temperature is equivalent to the mean of a variable one, provided that the variations are not very gross. It is clear, however, that the artificial feeding is much more favourable than under natural conditions; it results in quicker development, more eggs and a lower mortality in the laboratory than in natural infestations.

(i) Effects of 'normal' temperatures

*Rate of development*

The lowest temperature at which bed bugs will complete their life cycle is 13°C (55.4°F). Above this point, the speed of development increases in relation to the temperature in the usual way (see p. 56). Table 9 gives the average incubation periods for the eggs and the times for complete life cycles at various temperatures, assuming regular opportunities for feeding. (See also Fig. 8, p. 57.)

TABLE 9 *Effects of temperature on speed of development and resistance to starvation of bed bugs*

Temperature		Average in days			
°C	°F	Speed of development		Resistance to starvation	
		Incubation	Complete cycle	Males	Females
28	82.4	5.5	34.2		
25	77.0	7.1	46.0		
23	73.4	9.2	61.6	85 (136)	69 (127)
18	64.4	20.2	125.2	152 (260)	143 (225)
15	59.0	34.0	236.7	—	—
13	55.4	48.7	Not completed	338 (470)	360 (565)
7	44.5	No hatch	—	220 (386)	286 (465)

(After JOHNSON (1941) *J. Hyg.* 41, 345.) The figures in brackets are the maximum periods observed by Johnson.

The length of adult life depends upon temperature. With frequent opportunities of feeding, they live from  $\frac{3}{4}$  to  $1\frac{1}{2}$  years at normal room temperatures (18–20°C; 64–68°F), about 15 weeks at 27°C (80°F) and about 10 weeks at 34°C (93°F).<sup>(29)</sup>

*Feeding*

Bugs do not move about spontaneously and will not seek food at temperatures below 9°C (48°F). At higher temperatures, they will feed at various periods after

moulting (or hatching) ranging from about 6 days at 15°C (59°F) to 24 hours at 25°C (77°F).

The interval between one feed and the next depends, in the adult, primarily on the rate of digestion (which, of course, is regulated by temperature). The young stages, however, normally take only one full meal in each instar; the next meal is not usually sought until after the subsequent moult, the time of which also depends on temperature. At moderate temperatures (18–20°C; 64–68°F) the nymphs feed at about 10-day intervals and the adults feed weekly. At 27°C (80°F) the corresponding periods are approximately 4 and 3 days respectively.

### *Starvation*

The length of time which bugs will survive starvation depends to some extent on other factors besides temperature. The figures in Table 9 were obtained under the favourable conditions of high humidity (90% R.H.) and undisturbed rest in darkness; they refer to adults, which are more resistant to starvation than the younger stages. Therefore, these data are likely to exceed the periods of survival of bugs under natural conditions, which must be often adverse in one way or another.

It should be noted that the optimum temperature for survival without food is 13°C (55°F); below, as well as above this temperature, conditions are less favourable.

## *(ii) Effects of adverse temperatures*

### *Cold*

Bed bugs are fairly resistant to short periods of low temperature. The adults are killed by 2 hours exposure to -17°C (2°F) or 1 hour at -18°C (0°F); but 1 hour at -17°C (2°F) kills only about 25%.<sup>(29)</sup> Recently fed bugs are more susceptible than partially starved ones. Two hours exposure at -15°C (5°F) killed 76% of eggs.

Very prolonged moderately low temperatures (0–9°C; 32–48°F) such as might occur in unheated rooms in Britain during the winter, are unfavourable and result in considerable mortality of eggs and young stages. The eggs die in 30 to 60 days and the average life of first and second instars is 100–200 days under these conditions.

### *Heat*

Eggs of the bed bug are killed by an exposure to 45°C (113°F) for 1 hour, or to 41°C (106°F) for 24 hours. The thermal death points of adults are 1°C lower in each case. Atmospheric humidity is without effect in these relatively short exposures.<sup>(34)</sup>

Prolonged moderately high temperatures (say 34°C; 93°F), though not immediately fatal, are injurious and cause a mounting mortality in successive generations, which may eventually cause the extermination of a population.<sup>(25)</sup>

## *(iii) Food supply and egg production*

As already remarked, bed bugs will feed on a variety of warm-blooded animals and they develop and proliferate normally on these hosts. Quite often, bug infestations

occur in animal quarters of hospitals, in zoos, etc., in spite of the fact that many small animals such as rodents catch and eat a good number of them.

The data relating speed of development to temperatures given above, refers to optimum nutrition (i.e. bugs able to feed as often as they wished). If feeding is delayed or interrupted (though not to the point of actual death by starvation) the development of the bug is correspondingly prolonged.

The food supply available to the adult has a profound influence on egg production in the female. At 23°C (73°F) if the bugs are fed at 10–15-day intervals, there is a latent period of about 2 days and then approximately 8 eggs are laid over a period of 2–3 days. With more frequent feeding, the latent period is reduced; until finally, with two feeds per week, egg-laying is almost continuous, at the rate of about three per day. Towards the end of the bug's life, egg-laying becomes reduced and there is an increasing proportion of sterile eggs. The total number of eggs laid by a female in the course of the adult life, at 25°C (77°F), averages 345, of which about 5% will be sterile.

#### (iv) *Humidity*

Under normal conditions, humidity has only a slight influence on the biology of the bug. Low humidity (<10% R.H.) or very high humidity (99–100% R.H.) both have deleterious effects resulting, for example, in reduced hatching of eggs.

Under conditions of starvation, the lower humidities definitely curtail survival.

#### (e) **Propagation**

##### (i) *Dissemination*

Where two bedrooms adjoin, it is quite likely that bugs may travel from one to another and cause a new infestation, especially in ill-constructed houses. Bugs have been accused of spreading along a whole terrace of houses in this way, but there is very little definite evidence of the distances to which they will migrate. The fact that in an infested house the bugs are almost exclusively confined to bedrooms should cast doubt on the more extravagant rumours of their colonizing powers.

Infestation of new houses is almost exclusively due to bugs being carried to them passively. Owing to the fact that they do not remain long on the host, they are not often carried on people's bodies or clothing. Occasionally, however, bugs are carried on outer clothing (overcoat, collars, hats, etc.) on to which they have presumably crawled when the article in question was hung against an infested wall. Movable articles such as suitcases, are not infrequently infested and, during the Second World War, bundles of bedding taken to air-raid shelters were certainly responsible for dissemination.

Under normal circumstances, the usual way in which bugs get into new buildings is in furniture brought from an infested house, either directly, or via the second-hand furniture dealer. This has been a considerable obstacle to prevention of bug infestation in slum clearance rehousing schemes.

A final possible method of bug migration is in timber and other structures

taken as firewood, or for other purposes, from infested houses which are being demolished.

### (ii) *Population growth*

There are obvious difficulties which prevent the study of natural bug infestations over a long period. What knowledge we have depends on calculations from laboratory experiments based on temperature records in one or two representative bedrooms. The probable trends at different times of the year have been partly checked by observations on the composition of natural infestations observed on various occasions.

A very great deal depends upon prevailing temperature. Let us follow the calculations of Johnson (1941)<sup>(26)</sup> which are based on the supposition that an infestation begins in winter or early spring with, say, 40 adult bugs (20 females). They will not attempt to feed until the temperature exceeds 15°C (59°F) (mid-May); thereafter eggs will be laid which will result in another generation of adults, emerging in mid-August and onwards. Throughout the summer there will be progressive multiplication, depending on temperature and feeding facilities, until one to three thousand bugs of all stages are produced. The subsequent history in the following autumn and winter depends very much on whether the room is heated or unheated. In the latter case, feeding will cease in October and all the eggs, and perhaps 80% of adults and nymphs, will die of starvation during the long chill winter. By next spring relatively few bugs, mostly adults, will survive, and the cycle will be repeated.

In a room constantly heated in the cold part of the winter (e.g. a bed-sitting room) the bug population will continue to feed and proliferate during the winter months and a much larger population will be present at the beginning of the next spring.

### (f) **Importance**

Bed bugs feed exclusively on blood. They are adapted for living parasitically in human houses, feeding on man. However, they are not highly specialized parasites and will readily feed on other mammals or on birds.

Despite a considerable amount of experimental work, the bed bug has not been shown to be a regular disease carrier; it is certainly not so in Britain. Objection to the bug is partly on account of the unpleasant irritation (and consequent loss of sleep) caused in some people by the bites; but to a large extent it is an aesthetic abhorrence of what is regarded as a loathsome creature. This is augmented by the fact that bug infestation is usually associated with low hygienic standards. This is important; the spread of bugs into new housing estates drives away the more squeamish householders and depresses the standards of hygiene. To this extent, the bed bug may actually be a cause of slums as well as a characteristic feature of them.

Considerable progress in eradication of the bed bug from Britain was made during various slum clearance schemes in the 1930s.<sup>(31)</sup> Subsequently, the introduction of residual insecticides, especially DDT, facilitated the destruction of bugs and

further progress has been made, though not to the point of complete extermination (see Table 1, p. 10). This encouraging story could be repeated for various other civilized countries in the temperate region. In the tropics, unfortunately, progress has been held up by emergence of strains of bugs resistant to both groups of chlorinated residual insecticides. Both *C. lectularius* and *C. hemipterus* have been involved. Fortunately, this trouble does not yet seem to have arisen in Britain.

### (g) Control methods

It is generally agreed that bug infestations do not develop to any serious extent in houses where a high standard of domestic hygiene prevails. Therefore, every effort should be made to encourage and inculcate these ordinary cleansing measures.

For serious or chronic infestations, recourse must be made to insecticides. Since bugs spend most of the daytime in inaccessible harbourages, the only type of insecticide which can effect an immediate extermination is an efficient fumigant with good penetrating powers. Until recent years it was considered that this was the only treatment worthy of serious consideration. Houses were fumigated with sulphur dioxide (at 5 or 6 lb sulphur per 1000 cu ft) or hydrogen cyanide (at 12 to 16 oz HCN per 1000 cu ft).

Both fumigants required a reasonably well-built house to retain their fumes and moderate weather conditions (not too cold or too windy). The sulphur treatment was rather unreliable (owing to low toxicity to bug eggs and poor penetrating powers). The cyanide treatment was slow and expensive and, unless done by experts, dangerous. Though a fumigation might give a complete extermination, it had no persistent protective effect.

The advent of DDT provided a new weapon to attack bugs. The treatment kills the bugs only after they have come out of their crevices and walked over DDT deposits. However, these deposits remain insecticidal for many months and finally exterminate the colony. They also prevent reinfestation.

The treatment is very simple. About  $\frac{1}{3}$  gallon of 5% DDT in kerosene is required for a small infested bedroom. It is applied rather liberally (1 oz per sq yd) to the walls and to furniture likely to be infested (bed-frame) by a sprayer. In addition a *light* spraying may be given to mattresses, with especial attention to folds or seams. Should there be reason to suspect DDT-resistance, 0.5% solution of *gamma* BHC or 1% malathion could be used.<sup>(63)</sup> The treatment of bedding materials should be done with care, without soaking them; and it is probably advisable not to treat bedding of infants in this way. The rooms can be re-inhabited immediately after treatment without danger. The kerosene dries in one or two days and the smell dissipates in this time.

There is still a use for hydrogen cyanide fumigation in the disinfestation of furniture and effects when re-housing people from infested buildings. The fumigation should be done in a metal fumigation van provided with heaters, an air circulator and exhaust (see p. 136). Furniture collected in the morning can usually be delivered disinfested to the new house on the same day (excepting large stuffed armchairs, etc., which may require prolonged airing). Methyl bromide may also be used in the same way and does not demand such careful airing.

## II · FLEAS (Siphonaptera)

### (a) Historical note

The Goodman of Paris (1392) referred to in earlier chapters (p. 153 and p. 186) gives the following advice to his young wife for destroying household fleas:

I have heard tell that if you have at night one or two trenchers [of bread] smeared with glue or turpentine and set them about the room with a lighted candle in the midst of each trencher they [the fleas] will come and be stuck thereto. The other way I have tried and tis true; take a rough cloth and spread it about in your room and over your bed, and all the fleas that hop thereon will be caught, so that you may carry them away wheresoever you will.

The second remedy is certainly in accordance with the behaviour of fleas, since they are prone to burrow into and remain in rough cloth. The Goodman also observes that white blankets are best for the purpose, since they render the dark coloured fleas easy to see and catch.

### (b) Distinctive characters

#### (i) General

The fleas constitute a small order, only about 1000 species being known, but they are widely distributed about the world. Systematically they are a compact and isolated group, rather similar in form and without obvious affinities to other insects. The thorax is in a primitive segmented condition and never develops wings (though transitory wing buds may be seen in the pupae of some fleas). However, fleas display complete metamorphosis and are generally believed to have diverged from the primitive Diptera.

All fleas, in the adult form, are parasitic on warm-blooded animals. This is no doubt responsible for their degeneration, involving loss of wings and reduction or loss of eyes. The body is compressed laterally; it is 'streamlined' and covered with backward-directed bristles. These modifications assist in moving through fur or feathers on the host's body. Another well-known characteristic of fleas – their jumping powers – assists them in reaching their hosts and no doubt helps them to escape on certain occasions.

#### (ii) Identification of common genera and species

A key to the following common genera is given in the Appendix (pp. 447–448): *Pulex*, *Ctenocephalides*, *Ceratophyllus*, *Nosopsyllus*, *Spilopsyllus*, *Leptopsylla*, *Xenopsylla*.

The genus *Ctenocephalides* includes the cat and dog fleas, *Ct. felis* and *Ct. canis*. They may be distinguished as follows:

Forepart of the head (from front to 'crown' above antennae) longer than it is high. First teeth of genal comb nearly as long as the second.	<i>felis</i>
Forepart of the head as long as it is high. First teeth of genal comb only about half as long as second.	<i>canis</i>

(c) Life history (Fig. 24)<sup>51</sup>

## (i) Oviposition

Female fleas lay their eggs rather indiscriminately, either in the fur, feathers (or clothing) of their host or in the host's sleeping place. If they are confined to a box or tube, they will lay them quite freely on the bottom.

## (ii) Egg

The eggs are small, pearly-white, oval objects, without the definite egg-cap of bug or louse eggs. They are of the order of  $\frac{1}{2} \times \frac{1}{3}$  mm long, which is rather large for such small insects, and they may be distinguished with the naked eye.

When laid they are slightly sticky and may adhere to the pelt, plumage or clothing of the host. However, they are quite readily brushed off and they often fall on to the ground in or near the sleeping place of the host.

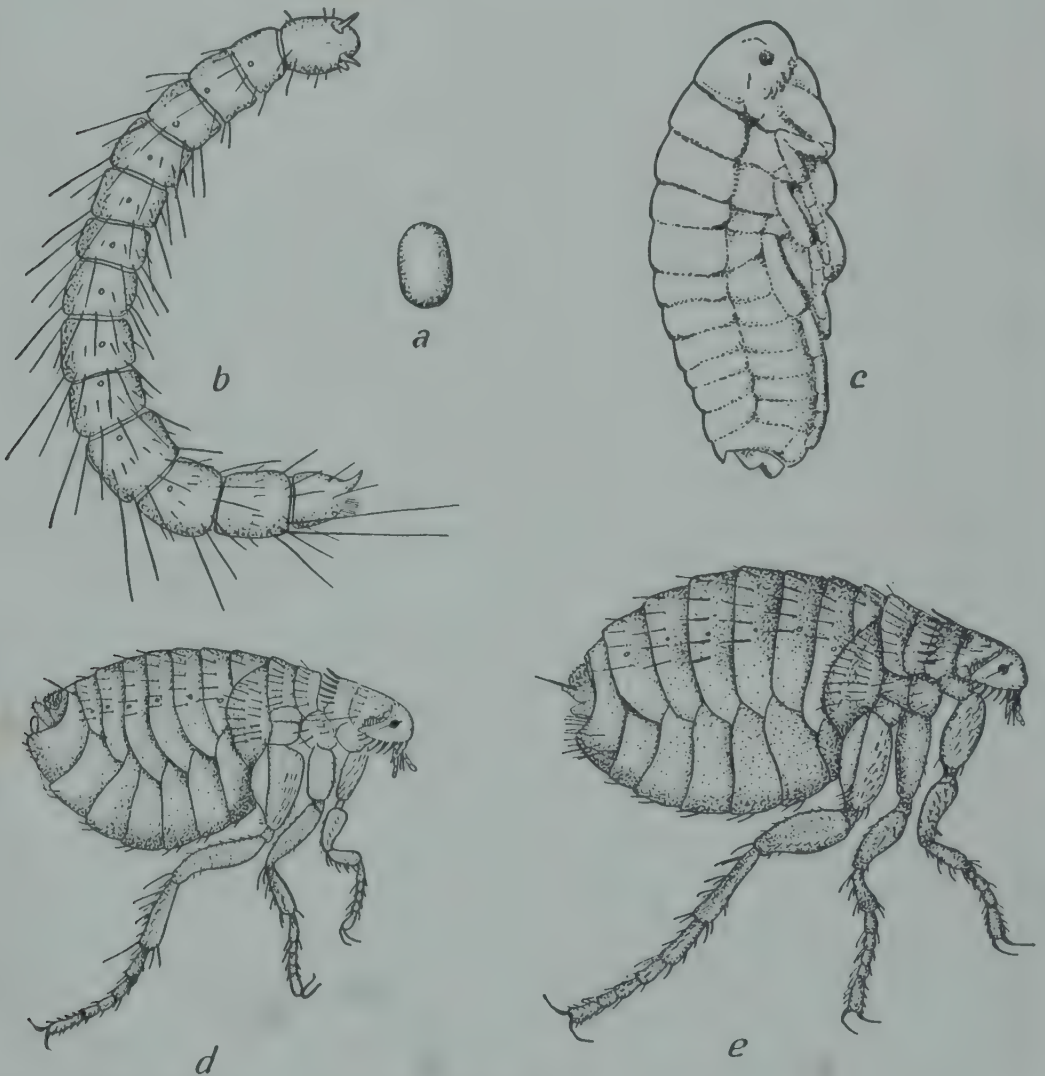


FIG. 24. Life cycle of a flea. (*Ctenocephalides felis*, the cat flea.) (a) egg; (b) larva; (c) pupa; (d) male adult; (e) female adult. (a), (b), (c) after Séguy (*Faune de France* No. 43). (d) & (e) partly after Herms (*Medical entomology*). All  $\times 20$ .

*(iii) Larva*

The larvae which hatch from the eggs are tiny, white, legless grubs. They are about  $1\frac{1}{2}$  mm long when newly emerged and eventually grow to about 5 mm in length. They are more or less cigar-shaped with a definite head, three thoracic and ten abdominal segments. The head bears a pair of single-jointed antennae, but eyes are entirely absent. The mouthparts include a pair of toothed mandibles, short brush-like maxillae and a labium, the last two bearing pairs of short sensory palps.<sup>(58)</sup>

The larva feeds on the miscellaneous organic debris to be found in the sleeping place of the host animal (particles of food, faeces, etc.); but an especially valuable element in the diet is the partly digested blood in the excrement of adult fleas.

The thoracic segments of the larva are similar to the abdominal ones; all of them carry rings of bristles (about 6–8 short ones and a similar number of long ones on each segment). A pair of spiracles is present on the thorax and on each of the first eight abdominal segments. The last abdominal segment bears a pair of peg-like processes which are used to thrust the animals forwards. With the aid of these and the above-mentioned bristles (which are directed backwards) the larvae progress quite rapidly with a kind of wriggling movement.

Flea larvae are very sensitive to loss of moisture and die on prolonged exposure to dry air. However, they normally live in a protected microclimate (see p. 55) which may be quite different from the general climatic conditions. Thus the air in a rat-hole, or under dirt and debris in an ill-kept sleeping place of a domestic animal, may be much more moist than the air of a room.<sup>(13)</sup>

The larvae pass through three larval stages and when they are fully grown they spin silken cocoons in which to pupate. These cocoons are irregular tent-like covers which often incorporate particles of dirt from their surroundings which may serve the purpose of camouflage. In the cocoon the insect changes into the pupal form.

*(iv) Pupa*

The pupa is of an ordinary type with the limbs free (i.e. not glued to the body). The general shape and appendages of the adult flea can be distinguished. From a creamy white, the pupa gradually darkens to a brownish colour, just before moulting to the adult stage.

*(v) Adult*

The adult flea does not emerge from the cocoon at once but remains quiescent for an indefinite period. It is stimulated to emerge and begin an active existence by vibrations which indicate the presence of a possible host. This is a useful adaptation for fleas which live in burrows or nests of migratory animals and it also explains why hordes of fleas sometimes attack people entering houses which have been empty for a considerable period. (The progeny of fleas of an earlier infestation, having reached the resting stage in cocoons under rubbish and in cracks in the floors, come out in response to the vibrations of people walking about near them.)

The shape of the adult flea is very characteristic and unlike that of any other insect. As already mentioned it is strongly compressed laterally and is usually easiest to examine when the flea is lying on its side.

The head is helmet-shaped and in some groups it is divided by a furrow, at the level of the antennae. The latter are short club-shaped appendages which can be tucked into a fold on the head when not being used. The antennae of certain male fleas are used to grasp the female during copulation. Eyes may or may not be present. They are rudimentary in form, which is not unusual in parasitic insects. It is uncertain whether they correspond to the ocelli of larvae or are degenerate compound eyes.

On the underside of the front of the head there is present, in many species, a row of short, broad, black spines, rather like a pronounced moustache. A similar row is sometimes present on the back of the first thoracic segment. These are simple but important aids to identification; they are referred to as the 'genal comb' and the 'thoracic comb', respectively.

In the adult stage, fleas take periodic meals of blood from mammals or birds. Nearly always, there is one warm-blooded animal on which they prefer to feed; but, whereas some species are virtually restricted to this particular host, others are more catholic in taste. Some, for example, attack a number of related animals, such as small rodents or nesting birds; others pass from one host to another according to chance contacts as from a rabbit to the fox which has killed it, or from a dog to its master. As might be expected, fleas are more ready to feed on an abnormal host if they are hungry.

The mouthparts, in both sexes, are modified for taking meals of blood exclusively. The piercing elements are the grooved labrum and a pair of sharp, sword-shaped mandibles, the concave inner sides of which form the sucking channel, together with the labrum. The maxillae are shorter, leaf-like structures with sharp points; however, they take no part in the piercing process, but carry four-jointed sensory palps. The labium is short and this too bears a pair of jointed palps which lie alongside the piercing elements, but separate from them during feeding.

Piercing is due to the probing action of the mandibles which are saw-edged at the tip. Saliva, from a short hypopharynx, runs down a groove on their lower edges into the wound. As usual, the blood is drawn up by a sucking-pump in the throat. There is no crop but a kind of gizzard with backward-directed spines, which is of prime importance in the transmission of plague (see p. 4). Normally the blood passes directly into the enlarged midgut and a part of it passes into the rectum and may be discharged at once, undigested.

The three thoracic segments are all freely movable and more or less similar. All the legs are highly modified for leaping and the feet also bear claws for clinging. On ordinary flat surfaces, fleas do not walk very well; but they can travel quite rapidly among fur or feathers. Leaping is useful for reaching the host or for moving from one host to another. The powers of leaping of fleas are sometimes exaggerated, however; they cannot jump upwards more than about 5 or 6 inches.

Different fleas vary in the proportion of their time spent on the host. Those species adapted to animals which regularly return to the same sleeping place tend to make relatively short visits to the host for food and spend much time in the nest, lair, kennel or bed. Other fleas are adapted to spend most or all their time on the host, though they can move to another host's body, if opportunity arises. This is

obligatory for bat fleas, for example; and the habit is shared by certain 'sticktight' fleas (e.g. the rabbit flea, in Britain).

The plates of the abdomen overlap smoothly. Like the thoracic segments, each one bears a row of backward-directed bristles. The eight dorsal plates each bear spiracles. At the hind end is a plate covered with small bristles and sense organs. Also, in the male can be seen the clasping organs of the genitalia.

The sexual organs are fairly complex and will not be described here. One important fact, however, must be mentioned. The female receives the spermatozoa into a blind pouch at the end of a tube leading from the vagina. This pouch (the 'receptaculum seminis') can be seen inside the female in specimens cleared and mounted as microscopical preparations. Its shape is used as a method of identification.

In copulation, the male takes up a position underneath the female and grasps her abdomen, which lies above him, with his antennae.

#### (d) Host preferences and distribution of important species<sup>(51)</sup>

##### *Pulex irritans*

The primary host is man, but it is sometimes found on various domestic animals (dogs, cats and various farm animals) on which it may rarely feed. Pigs are an exception, since *P. irritans* will feed on them readily and will breed in profusion in pigsties. The human flea is also found on certain British wild animals, including the fox, badger and hedgehog.

*P. irritans* is cosmopolitan and has been for so many years that it is impossible to be certain of its original source.

##### *Ctenocephalides felis*

*Ct. felis* breeds prolifically in association with the domestic cat and is also found on various wild animals of the cat family. It will also feed on dogs and fairly readily on man. Less commonly it occurs on rats, mice and other small mammals. It is cosmopolitan in distribution.

##### *Ct. canis*

The dog flea may attack other domestic animals (cats, rabbits, etc.) or man. It occurs on various wild animals related to dogs, such as the fox. It is cosmopolitan, but somewhat rare in the tropics.

##### *Ceratophyllus gallinae*

The 'hen flea' is, in fact, a common parasite of many wild birds, especially those which build nests in rather dry situations. It occurs in northern Europe, and part of Asia, but not on the wild jungle fowl from which our poultry were derived. It appears, then, to be a bird flea without strong host preference, which happens to thrive on the domestic fowl. When hungry, this flea may attack man.

##### *Ceratophyllus columbae*

The pigeon flea is related to the hen flea, but in contrast it is restricted in its choice of hosts to the domestic pigeon and the rock dove. Like *Ct. gallinae* it will occasionally bite man.

*Nosopsyllus fasciatus*

The primary host of the European rat flea is the brown (or Norwegian) rat. It will infest other rodents (e.g. the black rat and house mouse) but is less willing to attack other mammals. Thus, it never occurs on cats (though the cat flea will occur on rats). *N. fasciatus* rarely bites man.

Originating in northern Europe and Asia, it has now spread all over the world.

*Leptopsylla segnis*

Adapted to the house mouse, this flea occurs on other rodents, both commensal (rats) and wild. It can be induced to feed on man, but virtually never does so in practice. It is cosmopolitan.

*Xenopsylla cheopsis*

The tropical rat flea occurs on commensal rats and also on various wild rodents. It will very readily bite man, which accounts for its special importance as a vector of rodent diseases (especially plague) to man.

It is distributed widely in the tropics; but in Britain it is restricted to rat-infested areas near large seaports, to which it has been introduced by shipping.

*Spilopsyllus cuniculi*

The rabbit flea is a parasite of wild and domestic rabbits. It is one of the most sedentary of British fleas commonly attaching itself in the region of the ears. Sometimes it transfers itself to animals which hunt rabbits (e.g. to foxes and even domestic cats). It occurs throughout Europe.

**(e) Quantitative bionomics**

Investigation of the quantitative biology of fleas presents considerably more difficulty than similar studies on lice and bugs. The effects of simple environmental variables such as temperature and humidity are complicated by other factors which are either obscure or difficult to define. For example, certain common species like *Pulex irritans* are very difficult to rear under apparently favourable laboratory conditions. Again, the resistance of a flea to starvation may be greatly influenced by the nature of their surroundings; fur or cloth, into which they can crawl and remain quiescent, is more favourable than a bare glass tube in which they continually hop about and exhaust themselves. For these reasons, there are widely divergent data given by different authors and sometimes wide variations are observed in one investigation (e.g. survival of certain starved fleas of wild rodents in Russia were observed to vary from 4 to 292 days at 13–24°C (55–75°F) and 6 to 369 days at 1–15°C (34–59°F).<sup>(59)</sup>

Additional complications ensue from some inevitable idiosyncrasies of the various important species. Much of the existing work has been done with *X. cheopsis*, because of its importance as a plague vector.

**(i) Temperature**

High temperature has the usual effect of speeding up the development, the frequency of feeding and other processes, and of reducing the length of period of

TABLE 10 *Effects of temperature on speed of development and resistance to starvation (at 90% R.H.) of fleas*

Temperature °C      °F		Average in days				
		Speed of development			Resistance to starvation of <i>Nosopsyllus fasciatus</i>	
		Larval stage		Cocoon stage		
		<i>Pulex</i>	<i>Nosopsyllus</i>	<i>Nosopsyllus</i>		
30	85·6	13	16	5	12·6 (26)	13·0 (25)
23	74·5	19	20	10	11·1 (26)	12·1 (23)
18	64·5	38	30	20	22·2 (39)	15·7 (27)
10	50	105	100	50	—	—

Figures for development taken from data of BACOT (1914) *J. Hyg. (Plague Suppl. III)* and for starvation from LEESON (1932) *Parasitol.* **24**, 196. (Figures in brackets are maxima.)

resistance to starvation. Some data are presented in Table 10. The figures relating to development are taken from the most favourable averages recorded by Bacot; prolongation in other experiments is assumed to be due to unsuitable food, etc.

To the larval and cocoon periods must be added the incubation time of the egg. This seems to be about a week at moderate room temperatures and correspondingly more or less at other temperatures; precise data are lacking. As a rough guide, it may be estimated that the complete development of many domestic fleas occupies about a month in the British summer. The development of fleas indoors in the winter must depend, as with the bed bug, on the temperature maintained.

In a warm environment, with regular opportunities to feed, the adult flea lives for two to four months. At low temperatures the insect is sluggish and, under these conditions, the adult life may be prolonged to over a year.

#### (ii) *Food and egg production*

The food of the larva can vary in quality and, on an unsatisfactory diet, the development period is prolonged, irrespective of the temperature. As already mentioned the partly digested blood present in the faeces of the adult is an important ingredient in the diet of many larval fleas. The absence of this can be partly made good by addition of some other form of organic iron compound.

The food of the adult, being blood, is less variable in quality, but the frequency of opportunities to feed is an important factor. At warm room temperatures, fleas will feed daily if given the opportunity, and some species which spend much of their life on the host's body (*X. cheopis* and *Ct. canis*) apparently feed even more often; but under cool moist conditions they can survive for long periods with meals at one or two-monthly intervals. Below 13°C (55°F) they do not attempt to feed.

Very variable results have been found for the resistance of fleas to starvation. The figures given in Table 10 are for favourable humidity but the temperatures are rather high and the fleas were kept in bare glass tubes. At 8–10°C (46–50°F) the maximum periods observed by Bacot were: 125 days with *Pulex irritans*, 95 days with *Nosopsyllus fasciatus* and 38 days with *Xenopsylla cheopis*.<sup>(2)</sup> (See also p. 236.)

As a general rule, egg production is dependent upon feeding and, as with most mosquitoes, eggs are not laid until after a blood meal. About 4 to 8 eggs are laid after each feed and the total number finally can amount to several hundred.

## (f) Importance

### (i) Transmission of disease

Fleas are the vectors of two serious diseases: plague and murine typhus, which are essentially rodent infections which can be carried to man by rat fleas. Obviously the danger depends on the readiness with which the rodent fleas will bite man. Many fleas of wild rodents, as well as the European rat flea *Nosopsyllus fasciatus*, are very unwilling to feed on man; therefore they are never directly the cause of plague epidemics. In contrast, the tropical rat fleas of the genus *Xenopsylla*, willingly bite man and when they occur on the commensal black rat together with a source of infection, they constitute a potential danger of plague.

In Britain, both *X. cheopis* and the black rat are restricted in distribution and there is virtually no risk of a plague epidemic. In the past (fourteenth-century Black Death and 1665 plague of London) there have been epidemics in Britain. The black rat was probably more prevalent then but the identity of the flea vector is uncertain.

Fleas can also act as vectors of various tapeworms of domestic animals and rodents and these sometimes get transmitted to humans. The eggs of the tapeworm, in the faeces of the mammal, are swallowed by flea larvae (which live in dirt and debris). Inside the flea, the cestode develops to the 'cystercercoid' stage. Return to the vertebrate intestine is accomplished when a parasitized flea is swallowed. This readily happens when domestic animals or rodents attempt to kill the fleas by biting through their fur. On rare occasions, dead fleas may be swallowed on food or other objects by people (especially children) living in close contact with infected pets. A well-known example is the worm *Dipylidium caninum*, the vertebrate host being the dog (sometimes the cat) and the intermediate host being the flea *Ctenocephalides canis*. The rat and mouse tapeworms *Hymenolepis* sp., normally transmitted via rodent fleas, are also occasionally carried to humans.

### (ii) Annoyance from bites

#### *Species responsible*

Annoyance from the flea bites in present-day Britain are more likely to be due to cats, dogs or birds than to the human flea. Thus, of 21 infested houses in the north of England, 15 involved *Ct. felis*, 5 were due to *Ceratophyllus* spp. and only 1 harboured *P. irritans*.<sup>(8)</sup> Even in 1899, in Germany, half the fleas collected in infested dwellings and institutions were dog fleas.<sup>(22)</sup> Probably *Pulex irritans* is discouraged by good housekeeping, since it still abounds in primitive villages in the Near East.<sup>(57)</sup>

#### *Types of reaction*<sup>(6, 7)</sup>

Persistent attacks of fleas, of whatever species, may cause irritation and loss of sleep. People differ greatly in their reaction to bites, some being hardly affected,

others suffering a great deal. Infants, in particular, suffer from a papular urticaria and sometimes scratching leads to secondary infections, such as impetigo.

The primary reaction to flea bites is allergic in nature, induced by a constituent of the flea's saliva. The cause of sensitization appears to be similar to that due to mosquito bites. A person exposed to regular flea bites for the very first time may show no reaction; but if the attacks are continued, sensitization occurs. The first result is an itching papule, surrounded by reddening and swelling. This may persist for a few days. If bites are continued, an immediate skin reaction (in the form of a weal) occurs but disappears within an hour or so. Continued exposure often leads to desensitization, resulting first in the loss of the delayed (and more troublesome) reaction; and later the primary response may also fail to appear.

### (g) Control measures

Measures against fleas may be of two distinct kinds; protection against infestation of the person by adult fleas and eradication of breeding foci in houses.

#### (i) Protection

One or two fleas may sometimes be acquired in travelling or in visiting crowded places in certain urban districts. This may be unpleasant for the individual, but it is not serious provided that his home is kept clean, for it is very unlikely that an infestation will develop there. This occurrence is so rare for the majority of people that it is not worth taking regular precautions against fleas. However, certain people concerned with medicine or hygiene have to make regular visits to many flea-infested houses in the course of their duty. Such people may find it advisable to use preventive measures. Perhaps the most satisfactory, simple method is to apply repellents to the clothing around such areas as the socks and trouser ends, cuffs and neckband. Fleas need to pass these zones to reach the undergarments. Drops of repellent (e.g. dimethyl phthalate) smeared over the hands can be transferred to the garments by firm rubbing. A thorough application, though invisible, should remain effective for a week or two. Health Inspectors or workmen, who may have to enter very heavily infested rooms, should, in addition, wear gum-boots. These ensure protection from fleas jumping up from the floor.

An ounce of 10% DDT dust sprinkled in the underwear weekly will prevent fleas lodging there, but may not kill them sufficiently quickly to prevent them biting.

#### (ii) Eradication

An occasional flea bite is a minor discomfort, not to be compared with the constant attacks of an infestation in the home. Fleas cannot infest dwelling houses which are regularly swept and cleaned *throughout*; for the larvae from eggs laid by an occasional adult flea stand no chance of developing on a clean floor. The decrease in prevalence of fleas during the past 30 or 40 years is probably due to improved housekeeping and the widespread use of the vacuum cleaner.

If persistent trouble with fleas occurs in a building, there is probably an infestation (i.e. fleas are breeding) on the premises. The first essential is to find out the

type of flea which is prevalent; this will give a clue to the breeding site. It is even more important to extirpate the brood than to kill the adult fleas. The use of insecticides should be combined with thorough domestic cleansing, as there may be more than one breeding site; but if the cleaning is conscientiously done, no focus will escape attention.

### *Human fleas*

These usually infest and breed in bedrooms. If the infestation is heavy it may be advisable to dust the floor first with insecticide. The carpets and rugs are removed and cleaned or at least beaten. Bedding should be laundered. The floor should be carefully swept or cleaned with a vacuum cleaner. If the latter is not available, it is advisable to force up fluff and dirt from between the floor-boards with a knife. The floor should finally be scrubbed.

### *Cat or dog fleas*

The majority of complaints of fleas from well-kept houses can be traced to pet animals. They normally breed in the basket or kennel where the pet sleeps; but there may be other breeding sites in armchairs, etc. In addition, a number of fleas may be present in the animal's fur. Accordingly, both the animal and the breeding sites must be treated.

Fleas on the animal's body are best dealt with by dusting a finely powdered insecticide into the roots of the fur. A simple shaker type dispenser or puff duster is convenient. Particular attention should be paid to the back, neck and top of the head. About one tablespoonful of dust is needed for a medium-sized short-haired dog; and the amount can be adjusted according to the size or length of hair.

Suitable insecticide formulae are 5% DDT; 0.5% *gamma* BHC; 1% pyrethrins; 0.2% pyrethrins plus 2% synergist; 5% malathion.

The DDT, BHC or malathion should not be used on cats, which tend to lick them out of their fur.

The breeding sites should now be traced and should receive treatment. Rugs and pillows should be thoroughly shaken and then either washed or sprayed with insecticide. Straw and old rags or rubbish should be burnt. The basket or kennel should be thoroughly cleaned and, in bad infestations, sprayed with insecticide. Suitable formulae are emulsions containing 5% DDT; 1% malathion; 1% *gamma* BHC.

### *Chicken fleas*

Chicken farmers may be annoyed by chicken fleas. The hens may be treated individually with powder applications as described for pets (above). A heavy dusting of the chicken houses with 5% malathion may also be necessary (allow 1 lb to 40 sq ft).

## III · HUMAN LICE

### (a) **Historical note**

During the Dark Ages there was a curious reaction to worldly pleasures in the exaltation of dirt and vermin by Christian acetics. Lice were called the 'pearls of

poverty' and were a mark of saintliness. This attitude persisted at least until the twelfth century, as witnessed by the sequel to the murder of St Thomas à Becket, which happened in midwinter. The body lay in the cathedral all night, and next morning numerous woollen clothes were removed in preparing it for burial. It was recorded by a chronicler of the time that there were so many lice on the inner garments that they 'boiled over with them, like water simmering in a caldron'; and the onlookers burst into alternate fits of weeping and laughter, between the sorrow of having lost such a leader and the joy of having found such a saint.

Even when lice became generally unpopular, they still continued to vex people in high places. Anne, Countess of Dorset, in the seventeenth century complains: 'we were all lousy by sitting in Sir Thomas Eskine's chambers'. While Pepys in the same century complains more than once of nits in his periwig. Only 180 years ago, Burns, in his poem 'on seeing a louse on a lady's bonnet at church' admits

*I had na been surprised to spy  
You on an auld wife's flammen toy;  
Or aiblins some bit duddie boy  
ons wylie coat.*

### (b) Distinctive characters

#### (i) General

Human lice belong to a small degenerate order of insects, all of which are blood-sucking ectoparasites of mammals. Eyes are reduced or absent and the mouthparts are highly modified for piercing and sucking. Their bodies are greyish, leathery and translucent. The legs end in single claws, articulated so as to grip the host's fur. No traces of wings are developed.

#### (ii) Genera and species concerned

The three varieties of human lice are all sucking lice of the family Pediculidae which contains the lice of men and monkeys. The members of this family are unique in possessing eyes, which distinguishes them from other sucking lice.

Human lice belong to two species: *Pediculus humanus* (which exists as two varieties *P. h. capitis*, the head louse, and *P. h. humanus*, the body louse) and *Phthirus pubis*, the crab louse or pubic louse. *Pediculus* and *Phthirus* are quite easily distinguished, though fairly closely related.<sup>(15)</sup>

1. All legs about equally strong (but anterior legs of male stouter than those of female). Abdomen about twice as long as it is broad *Pediculus*
2. Foreleg slender with long fine claw; mid and hind legs strong with thick claws. Abdomen compressed and broader than long *Phthirus*

The two varieties of *P. humanus* are very closely related. Anatomically they differ principally in averages of size and proportion, but the extremes of all measurements overlap. Therefore, it is impossible to assign an individual specimen to either variety with certainty, though that should be possible with quite small samples, provided that they are measured under comparable conditions. Unfortunately, many of their dimensions vary greatly with the time elapsing since feeding, so that

measurements are unreliable unless that can be standardized. Generally, body lice are about 10 to 20% larger than head lice. In addition, head lice tend to have relatively thicker antennae, deeper indentations between abdominal segments and less well-developed abdominal musculature.

The two forms are rather similar in physiological characteristics but the body louse form is definitely more efficient (more eggs, longer life, greater resistance to starvation) at least under experimental conditions. However, the most important difference between the two forms lies in their habits, which induce one form to inhabit the scalp and the other to live amongst the underwear. It seems not unlikely that the *capitis* race was the original type adapted to man before he began to wear clothes and that *corporis* is a new strain adapted to the more difficult life among movable (and removable) clothing.

Some doubt has been cast on the validity of these two strains of lice. It has been suggested that their differences are merely due to differences in environment and that head lice, reared on the body, will sooner or later acquire the characteristics of body lice. A fairly careful quantitative examination of this theory, however, has not confirmed this. It is most likely that the segregation of the two forms into 'good' species is hindered by their imperfect isolation. Cross-mating will readily occur in captivity.

### (c) Life history<sup>(15)</sup>

#### 1. The head louse (*Pediculus humanus capitis*) (Fig. 25b)

##### (i) Oviposition

The females lay eggs on the hairs of the head near the scalp. The lower part of the egg, when it is laid, bears a quantity of adhesive material which glues it to the hair on which the female deposits it. This cement is extremely persistent and retains the empty egg shell long after the young louse has emerged. Thus, the hair of an infested person will contain numerous 'nits', some of them viable, but many empty and harmless. 'Nits' may often be seen several inches down the hairs, but these have usually been carried out by the growth of the hair, in which case they are certainly empty or dead. No method is known of dissolving this cement without harming the hair or the scalp; certainly the idea that vinegar or acetic acid will attack it is false.

##### (ii) Egg

The egg of the louse is approximately oval and rather large for the size of the insect, being about  $0.8 \times 0.3$  mm. Viable eggs are pearly yellowish-white and opaque; after hatching they become translucent and opalescent. With a little practice, hatched and unhatched eggs can be discriminated with the naked eye, or with a low-power magnifying glass.

At the top of the egg is an egg-cap which falls off like a manhole cover when the insect emerges. An area on this cap bears a variable number of cell-like air cavities pierced at top and bottom so that atmospheric air can reach the embryo in the egg. Towards the end of the incubation period, the dark eyes and other structures of the young insect can be seen through the shell.

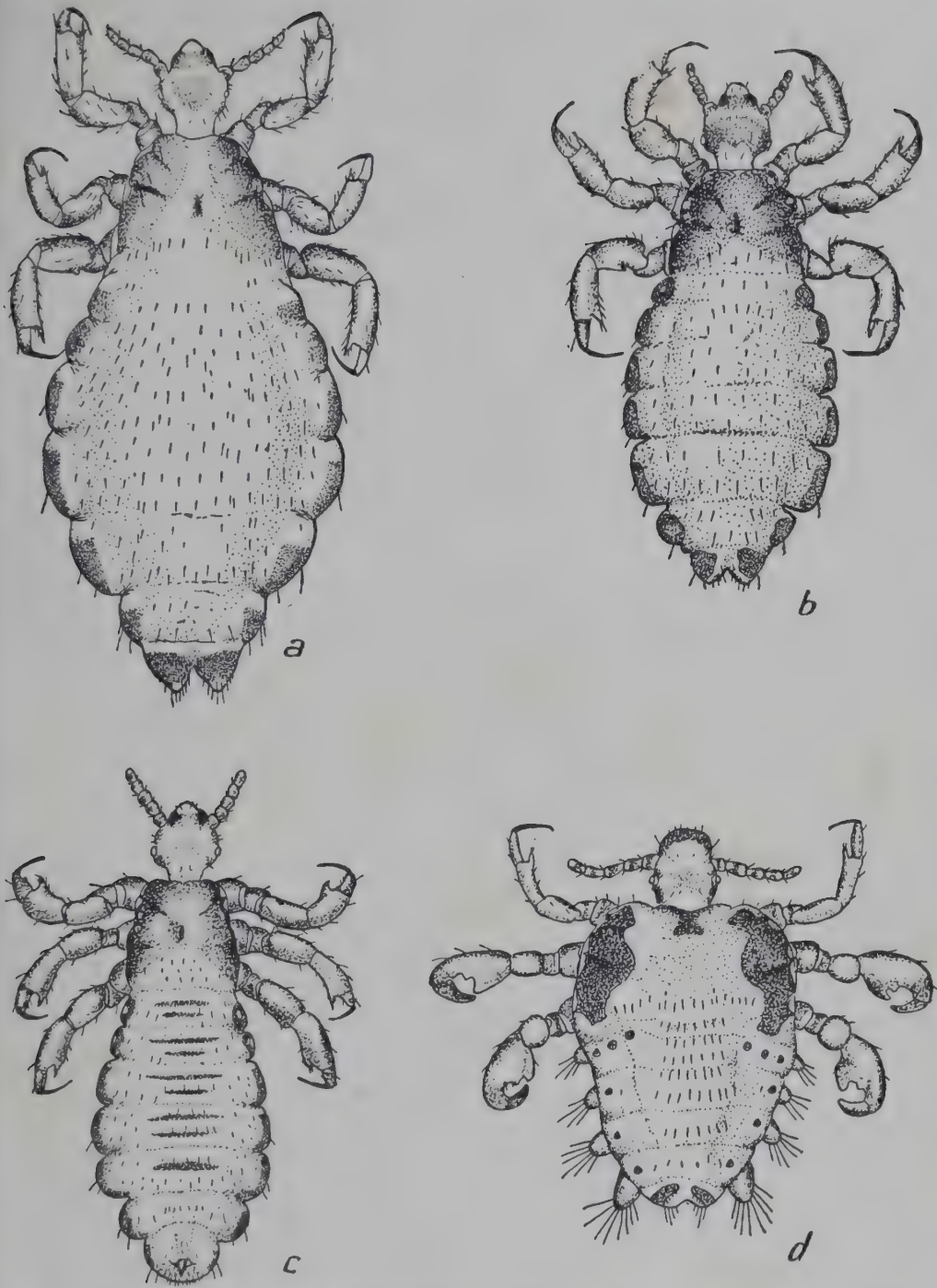


FIG. 25. *Human sucking lice*. (a) *Pediculus humanus corporis* (body louse) female; (b) *P. humanus capitis* (head louse) female; (c) *P. h. capitis* male; (d) *Phthirus pubis* (crab louse) female. After Ferris, *Monograph on the sucking lice*, Stanford Univ. Public. Biol. Sci.) (All  $\times 22$ .)

### iii) Nymph

The cuticle in all stages of the louse is partly transparent so that some of the internal organs can be vaguely seen in living specimens. Over most of the abdomen the cuticle is flexible and allows the volume of the insect to increase considerably after a meal of blood.

The first stage nymph is straw-coloured. It is able to feed shortly after emergence and the first blood meal is visible through the cuticle, giving the young insects the appearance of tiny rubies. Later, digestive processes cause the blood to blacken and the gut in older lice is usually purplish-black. Feeding occurs at fairly frequent intervals, at least twice daily.

There are three nymphal stages and after the third moult the insect reaches the adult stage. Anatomically, the nymphs are very similar to the adults, the chief differences being (1) size and proportions, (2) absence of external sexual organs in nymphs.

#### (iv) *Adult*

Adult lice vary in colour from a dirty white to greyish-black. The pigmentation is most pronounced in the harder parts of the cuticle. The colour of the adult louse, which cannot be altered, is largely an adaptation to the background during nymphal life. Lice from blondes, therefore, are paler than those from people with black or brown hair.<sup>(12, 23, 48)</sup>

The head bears a pair of antennae which are together waved from side to side with a characteristic testing motion as the insect advances. The eyes are poorly developed, which is compatible with the retiring parasitic habits of the louse. The mouthparts are anomalous in being withdrawn into a pouch in the head so that they are not normally visible. The mouth of the pouch bears recurved teeth which, in feeding, are pressed into the skin of the host to anchor the head in position so that the piercing mouthparts can enter with ease. These comprise three superposed stylets, the exact homologies of which are not known. The upper and lower stylets, which are paired in origin, form the food channel; the intermediate stylet carries the duct from the salivary glands. As already remarked, the saliva causes irritation and resultant scratching may lead to skin infections.

The thorax of the adult louse bears no trace of wings. The legs are powerful and curiously modified for clambering among hairs. A strong terminal claw grasps the hairs by apposition against a peg-like projection higher up the leg. Lice are not very rapid walkers; a distance of 23 cm in a minute has been recorded for body louse adults at 20°C, and head lice, though said to be slightly more active, would not greatly exceed this. Both types of louse are repelled by light and walk away from it.

On the abdomen, the hardened plates of the cuticle are restricted to lateral lobes and some narrow strips on the back of the male; the remainder is flexible and leathery. The hind end of the abdomen of the male is pointed, with the anus and sexual orifice just dorsal to the tip. In the female, the abdomen ends in two triangular projections which can be distinguished with the naked eye and this enables the sexes to be distinguished with ease.

In copulation, the male gets beneath the female and grasps her hind legs with the (specially enlarged) claws of his front legs. He curves up his abdomen and inserts a very complex penis into her genital aperture. The union persists for a considerable time and united pairs often may be found walking about and feeding normally.

After mating, the female will lay viable eggs for a variable period up to three weeks.

## 2. The body louse (*Pediculus humanus humanus*) (Fig. 25a)

The life history of the body louse is very similar to that of the head louse; the principal differences (apart from quantitative ones, which will be discussed shortly) being in certain habits.

The eggs are glued to fibres of the clothing in the same way as those of the head louse are cemented to hairs. Occasionally the body louse attaches its eggs to the body hairs. There is a tendency for large numbers of eggs to be laid in restricted areas where lice congregate, especially along the seams inside of the garment next to the skin.

The hatching of the eggs, the feeding, growth and moulting of the nymphs and the mating of the adults occur exactly as in the *capitis* race. All stages of body lice spend most of their time on the clothing, especially on the inside of the undergarment next to the skin. They are gregarious, being attracted together by the smell of each other and of their excrement,<sup>(62)</sup> and they tend to congregate along the seams of garments, as already remarked.

Body lice probably prefer to visit the skin to feed when their host is sitting or lying quietly. Apart from their visits to the skin, they wander about to a considerable extent among the clothing<sup>(10)</sup> (especially the older nymphs and adults) and they are particularly active when their host becomes hot. However, smaller and smaller proportions of the louse population are found on successive garments away from the skin.<sup>(29)</sup> Only on very heavily infested individuals can lice be seen walking about on the outer clothing.

## 3. The crab louse (*Phthirus pubis*) (Fig. 25d)

Relatively little is known about the detailed biology of *Phthirus* because it is a difficult and unpleasant insect to rear in captivity. The life history is not greatly different from that of *Pediculus*.

The egg, for example, is similar but smaller with a somewhat more convex cap. It is laid on a body hair, to which it is glued like the egg of *Pediculus*.

There are three larval stages leading to the adults. All stages are very much more sedentary than head or body lice. They tend to settle down at one spot, grasping hairs with the legs of both sides of the body, inserting the mouthparts and taking blood intermittently for many hours at a time. The legs are adapted to grasping rather large hairs and, in the position adopted, the adult prefers hairs rather widely spaced (compared with the dense hairs of the head). This may partly explain the distribution of the crab louse which is most commonly found on the hair in the pubic and peri-anal regions. It is also found on other hairy parts of the thighs and abdomen and sometimes in the axillae, eyebrows, eye lashes and around the scalp.

### (d) Quantitative bionomics

Lice are different from most other insects in being comparatively uninfluenced by climate. Their habitat, close to the human skin, ensures for them an environment with a warm, fairly constant temperature (about 30°C; 86°F) and moderately high

humidity. They have few enemies and abundant food supply. Adaption to this easy life has resulted in lowered resistance to unfavourable conditions. Though they can survive short exposures to cold and heat, they will not grow or develop at moderate or cool temperatures but require conditions like their normal habitat. They soon starve to death in the absence of a host.

The susceptibility of lice away from the host depends on their degree of independence; the sedentary crab louse is most sensitive, while the body louse, which may be removed nightly with clothing, is most resistant.

### 1. Head and body lice

The results of a quantitative study of the two races under similar conditions is given in Table II. In these experiments the lice were kept in breeding boxes and worn on the body for various proportions of the 24 hours. Lice living permanently on the body have an incubation period of 8–9 days and a nymphal life of similar length. The complete life cycle thus occupies about 18 days, but this may be prolonged if the lice are periodically removed from the body (e.g. in clothing removed

TABLE II. *Bionomic data obtained with head and body louse strains*

	Averages for							
	Head lice				Body lice			
Worn on body (hours per day)	24	12	2 × 3	3	24	12	2 × 3	3
Incubation: days at 30°C	8.5	—	—	—	8.5	—	—	—
Nymphal period (days)	8.5	12.2	17.6	23.0	8.3	12.8	17.5	24.3
Development mortality (%)	15	35	32	97	0	9	9	64
Male adult life (days)	10	—	—	—	20	30	30	13
Female adult life (days)	9	22	17	—	20	21	25	15
Eggs per female per day*	7.5	4.3	2.6	—	11.1	5.7	3.4	1.7
Total eggs per female*	57	56	22	—	110	98	73	15
Hatch (%)*	88	76	64	—	94	91	78	0
Fatal starvation (hrs) at 23°C	—	55	—	—	—	85	—	—
Fatal starvation (hrs) at 30°C	—	<24	—	—	—	45	—	—

Data from BUSVINE (1948) *Parasitol.* 39, 1.

\* Over period of maximum egg production.

at night). It will be observed that the speed of the development is exactly the same in both races. In other respects, however, the *corporis* race is more efficient, at least, in captivity. Under these conditions, body lice show much less mortality during development, longer adult life, more eggs per female, a greater proportion of which hatch and a greater resistance to starvation.

The environment of the head louse is very equable and the insect is able to feed at any time. The body louse, on the other hand, can only feed undisturbed when the host is resting. It has been suggested that its larger size is connected with the

necessity for taking relatively infrequent large meals. Certainly it needs to be rather more resistant to starvation than the highly susceptible head louse.

## 2. The crab louse

At the temperature of the skin, the egg hatches in 7–8 days and nymphal development occupies 13–17 days. Adult life is apparently rather less than a month. Egg-laying is at a lower rate than in *Pediculus* but records are scanty; one female was observed to lay 26 at the rate of 3 per day.

Of 200 adults removed from the body, only one was able to survive for 24 hours.

## (e) Parasitology and abundance

### 1. Head and body lice

#### (i) *Growth of louse populations*<sup>(15)</sup>

If any infestation begins with a single pregnant female, the subsequent population growth can be calculated from the data in Table 11. The populations to be expected after three months, under moderate and under rather unfavourable conditions, have been estimated on this basis. The numbers of active stages calculated were 4000–5000 and 400–500 respectively. Now these figures are very rarely encountered in natural infestations even amid a large number of chronically lousy people. Since there are no parasitic or predatory enemies of lice, it must be assumed that the principal checks to population growth are the actions of the infested person in removing and destroying the parasites. The efficiency with which these measures are done depends upon the hygienic standards of the infested individuals, the facilities available and to some extent on their sensitivity to louse bites.

#### (ii) *Numbers of lice on infested people*<sup>(32, 50)</sup>

Examinations of people infested with either head or body lice have always revealed that the majority of lousy individuals carry quite small numbers of lice, of the order of a dozen or so. Smaller and smaller numbers of people are found with populations up to several hundreds, while infestations of one or two thousands are very rare.

#### (iii) *Liability to infestation*

The difference in habits of the *capitis* and *corporis* races which induces one to live on the scalp and the other to live amongst the underwear, results in two quite separate problems of public health. These problems are most distinct in the more modern countries where improved standards of hygiene (especially the regular laundering of underwear) have relegated the body louse to a minor problem in peace time. The people infested by it are mainly vagrants; transitory inhabitants of the casual ward or common lodging house. Others are solitary, indigent folk; the worse cases are usually elderly and often infirm.

The head louse, on the other hand, is disturbingly common in some industrial areas. It attacks quite a different section of the population, mainly girls and young women, often of quite cleanly habits. Sometimes, indeed, the parasite has benefited

from misguided vanity when the regular combing of the hair has been avoided in order to preserve the 'set' of a permanent wave.

We owe a great deal of our knowledge on the bionomics of head lice to the investigations of the late P. A. Buxton and K. Mellanby. Buxton studied the numbers of lice found in crops of hair taken from the occupants of hospitals and jails in different parts of the world. Irrespective of locality or race, the general trends were consistent; and these have subsequently been shown to hold good in Britain. Very briefly the conclusions were these: there is a strong positive correlation between weight of hair (which is the best measure we have of length of hair) and infestation. On account of their generally longer hair, girls and women are more liable to infestation than men and boys. There is a negative correlation with age, children being more infested than adolescents, who are more infested than adults. The heaviest rates of infestation are found in groups showing the highest proportion of infested people.

Mellanby tried to obtain an estimate of the general level of head louse infestation in Britain, taking as a reasonably unbiased sample the records of examinations on entry to fever hospitals. The results (based on the years 1938-9) were very disturbing, for it appears that nearly 50% of girls of middle school age and 30-40% of boys showed evidence of infestation. These figures were for urban districts; children in rural areas were much less badly infested. Later surveys showed little change in 1943,<sup>(36, 40)</sup> but some definite improvement by 1947.<sup>(33)</sup> More restricted records, from a single large city, showed very substantial reduction over the period 1940-7. Subsequently the decline in infestation continued at a slower pace and remained at a low level, with no appreciable decline, between 1957 and 1960 (see Table 1, p. 10).

Comparing the proportions of children infested in families of different size, it was found that the percentage increased with the number in family.<sup>(39)</sup> An examination of the figures for recruits to one of the women's services revealed that infestation was most common among the less intelligent groups as revealed by intelligence tests.<sup>(55)</sup> These two accounts illustrate the association of head louse infestation with poverty and ignorance.

#### (iv) *Transmission*

The ways in which lice travel from one person to another are still largely a matter of conjecture. Transmission by fomites must occur to some extent, but this is limited by the comparatively short survival of lice away from the body. It seems that infestations are usually due to regular association of a moderately intimate nature with an infested person.

Children occasionally acquire head lice at school, probably during play. Lice readily spread through the family group and it is a common experience of school medical officers that children, disinfested at school, are repeatedly reinfested at home. Young children or adolescents outside the school age group, and not subject to frequent inspection, are often responsible for this.

Body lice may be acquired from bedding or furniture recently used by an infested person (e.g. the beds in common lodging houses). However, lice are not found in large numbers or for very long afterwards in such bedding or furniture. The most

favourable circumstances for rapid and universal spread of lice is when people sleep in their clothing and huddle together for warmth (e.g. trench warfare in winter).

## 2. The crab louse

Very little is known about the rate of infestation of *Phthirus* in any human community. It is much rarer than *Pediculus* and the available evidence suggest that only about 3 or 4% of people infested with lice suffer from *Phthirus*.<sup>(49)</sup>

In view of the sedentary habits of *Phthirus* and its normal occurrence in the pubic region, it is likely that crab lice are often transmitted from one person to another during sexual intercourse. However, it is possible that it may spread in other ways (towels, water closets, bedding, etc.) by loose hairs dropped by infested persons. These must account for the occasional infestations of infants' scalps and the eyelashes of individuals who have no pubic infestation.

### (f) Importance

Human lice can transmit certain dangerous diseases. They are the vectors of two rickettsial diseases (exanthematic typhus and trench fever) and they can carry a spirochaete infection causing a relapsing fever. These diseases are absent from Britain and other north-western European countries. It appears that, under experimental conditions, both races of *P. humanus* can be used to transmit these diseases in the laboratory, but the major epidemics of the past have been all associated with widespread *corporis* infestation. Furthermore, the areas where they remain as endemic diseases are places where *corporis* infestation is not uncommon; whereas *capitis* infestation is still comparatively frequent in disease-free zones.

Very little is known about the importance of *Phthirus pubis* as a transmitter of human disease. However, it is rarely very abundant and lives a very sedentary life so that it is unlikely to spread disease rapidly through a community.

All types of human louse cause the usual irritation resulting from the bites of bloodsucking insects. The pruritus is due to the saliva of the insect and there are many degrees of reaction to the bites from slight irritation to severe urticaria. Very long-continued infestation results in a thickening and pigmentation of the skin known as 'vagabonds' disease'. The bites of *Phthirus pubis* also frequently cause characteristic small blue spots, about 0.2 to 3.0 cm in diameter, with an irregular outline. These appear some hours after the crab louse has bitten and persist for a number of days.

The irritation caused by louse bites may be severe enough to cause loss of sleep. Scratching of the bites frequently causes abrasions which become infested with *Staphylococci* and other organisms which normally occur on the skin, leading to impetigo, furunculosis or eczema. Impetigo in school children is not infrequently due originally to *capitis* infestation and cannot be satisfactorily eliminated until the parasites are removed.

Apart from these unpleasant results of louse infestation, the insect itself occasions considerable disgust and feelings of shame which, unfortunately, sometimes lead to infestations being hidden or denied. These retrograde actions may be due to the

belief that certain people are 'breeders' of lice and are therefore incurable. Another source of shame and concealment is that *Phthirus pubis* is commonly considered to be a venereal infestation, though it may be acquired in other ways.

### (g) Control<sup>(11, 63)</sup>

The primary difficulty in finally eradicating louse infestations is the problem of reinfestation. Lousiness seldom occurs in isolation. With head lice the family is the usual infested group; with body lice the infested group is a number of people living under unhygienic conditions, varying from a few tramps or a number of prisoners in a primitive jail, to a host of refugees. Individuals deloused by evanescent methods soon become reinfested from their associates. This trouble is augmented by the tedious nature of the older delousing methods which made it impossible to disinfest large numbers in a short time.

Modern anti-lice insecticides are an improvement in two respects: (i) they are persistent and give some protection from reinfestation, (ii) they are quick and easy to apply.

As already remarked, the different habits of the head and body races of lice and the different types of people infested give rise to two quite distinct public health problems; and this affects the choice of control measures.

#### 1. The head louse (*Pediculus humanus capitis*)

##### *Insecticides*

To be successful, an insecticide preparation for head lice must be acceptable to the patient; otherwise there will be efforts to avoid treatment and substances applied under protest will be washed off as soon as possible. In contrast, an effective application which is invisible and virtually odourless will be acceptable, and the patient may facilitate treatment of other members of the family suffering from the same complaint. In Britain, where the majority of infested people are girls or young women, an aqueous preparation has been found least objectionable. An emulsifiable concentrate containing 1% *gamma* BHC in alcohol ('Lorexane') is diluted with 5 parts of water before applying to the roots of the hair. In America, an emulsion concentrate known as NBIN has been used. It contains 68% benzyl benzoate, 6% DDT, 12% benzocain and 14% 'Tween 80' (an emulsifier).

Although suspected cases of DDT-resistance in head lice have been reported, none has been confirmed. For normal lice, a single treatment should eradicate about 95% of infestations. The patients should all be inspected after about 10 days to check the success and preferably apply a second treatment in any case of doubt.

It may be considered worthwhile giving small quantities of the insecticide for home use by other members of the family who may not be available for treatment.

##### *Combing, etc.*

In early days head lice infestations were treated by shaving the head or at least cutting the hair short. This drastic procedure is no longer essential, but in very bad cases some shortening of the hair may be desirable.

None of the insecticidal substances described (in fact, no known substance) will

dissolve the cement that binds the nits to the hair without damaging the latter. Thus they may cure infestations but leave dead or empty nits in the hair. This may be regarded as unsightly or may confuse health inspectors who may not be able to distinguish live and dead nits. Therefore it is desirable to remove them.

Nits can be removed by thorough combing with a fine-toothed *metal* comb, of the type made by Messrs Saker. Combing alone may be undertaken to cure an infestation; but it must be done very thoroughly. Since this takes at least 20 minutes, and gives no protection against reinfestation, it is not recommended.

## 2. The body louse (*Pediculus humanus humanus*)

### *Insecticides*

Application of powder insecticides is the ideal way of rapidly treating large numbers of infested people (e.g. refugees, prisoners of war, etc.). 10% DDT dust is the insecticide of choice unless resistance has been reported; in that case 1% malathion is the next choice followed by 1% *gamma* BHC or 0.2% pyrethrins plus 2% synergist. About an ounce of the dust selected is scattered among the underwear and rubbed into the seams, kills all lice and gives protection from reinfestation for about three weeks. Although the eggs are not killed, this gives ample time to destroy the young nymphs as they hatch.<sup>(28)</sup> Where it is important to treat large numbers of people rapidly, the dust can be applied, without their undressing, by introducing the nozzle of a dusting gun under the clothing at several points. (Up each sleeve, down the neck each side back and front and under trousers or skirt at the waist band.)

People in uniform who have to live in louse-infested areas may obtain even longer protection by wearing DDT-impregnated underwear. DDT impregnation can be done from solution (in white spirit) or emulsion to leave 1% by weight of DDT on the cloth. This should be done from some centre and the treated clothing distributed therefrom. This treatment will last for 6–8 weeks, even with regular laundering of the underwear.<sup>(46)</sup>

### *Other methods*

In civilized communities, cases of body louse infestation are rare and treatments sporadic. Vagrants may be sent to a public cleansing station or prisoners entering jail may require delousing. Reinfestation may present no problem and it may be convenient to obtain rapid disinfestation by heat treatment or fumigation. At the same time, the infested individual would be bathed. Disinfestation by hot air is described on page 83. Many local authorities find it convenient to use a steam sterilizer, though the heat generated is excessive and certain articles of clothing may be spoilt.

Fumigation in a simple metal drum or plastic bag can be done, using one of the liquid fumigants in Group II (Table 6). Ethyl formate has been shown to be simple and effective, used in this way.<sup>(12a)</sup>

## 3. Crab lice

As with head lice, the earlier treatments involved shaving or cutting of the infested hair; but this should not be necessary. The simplest and most satisfactory method

is the application of one of the modern insecticides and a repeat treatment one week later to kill any young nymphs hatched from unaffected eggs. DDT 10% dust, *gamma* BHC 0.6% dust or a 2% DDT or 0.2% *gamma* BHC emulsion should be suitable. The Lethane oil treatment should not be used because it might cause dermatitis of the genitalia. In treating phthiriasis of the eyelashes, it is best to use a Vaseline ointment containing pyrethrins and remove the insects with fine forceps, having applied cocaine to the conjunctiva if necessary.

The centuries-old use of mercuric ointment for crab lice cannot be recommended. Its insecticidal value is low and there is some risk of mercurial poisoning.

#### IV. LICE OF DOMESTICATED ANIMALS

Two types of lice are parasitic on animals: biting lice (order Mallophaga) and sucking lice (order Siphunculata). The Mallophaga have chewing mouthparts and feed on pieces of feather, fur, sebum and fragments of scurf from the host's body; some of them also nibble the skin and drink the blood that exudes. Most, but not all of them, are parasitic on birds. The Siphunculata, which are all parasites of mammals, have highly specialized mouthparts for piercing the skin and sucking blood.

The host preferences of both types of lice are rather rigid. The entire life cycle is spent on the host; and lice rarely, except accidentally, transfer to a different species. If they are removed from the host, lice die within a few days. This is understandable with sucking lice, for they die of starvation. But it is also true of bird lice, which cannot survive away from the host, even if given feathers to feed on.

##### (a) **Sucking lice** (Siphunculata)<sup>(17)</sup>

There are about 200 species known and these are grouped into four families. The following list includes some of the more common species.

###### (i) *On dogs*

*Linognathus setosus* (Fig. 26b). This is a parasite of the domestic dog in many parts of the world. It is usually a parasite of long-haired game dogs and occurs on the back, flanks and at the base of the tail. Somewhat like *Pediculus* in form, it lacks eyes and has a wider abdomen. Approximate lengths: male 1.5 mm; female 2 mm.

###### (ii) *On pigs*

*Haematopinus suis* (Fig. 26a) occurs on wild and domestic swine. It is one of the largest of the Anoplura, the female averaging about 5 mm and the male 4 mm in length.

Infestations of *H. suis* sometimes have a surprising result. The eggs of this louse are cemented to hog bristles in the same way as those of human lice are glued to hairs. Occasionally such bristles are used in the manufacture of hair brushes. They may escape notice for some time until sudden discovery gives rise to alarm. They appear to be 'nits' of some super head louse; but of course they are dead and harmless.

(iii) *On horses*

*H. asini* is rather like *H. suis* but smaller (female 3 mm; male 2 mm) and with a proportionately larger head.

(iv) *On cattle*

*Linognathus vituli*, *Solenopotes capillatus* and *Haematopinus eurysternus*.

(b) **Biting lice** (Mallophaga)

Biting lice are small or very small (0.5 to 6 mm long) flat-bodied insects of rather characteristic appearance. There are about 1700 species known, divided among four families.

The breeding habits and life history of a biting louse are not very different from those of sucking lice. The eggs are cemented to the bases of feathers or hairs and incubate there. The whole life is spent on the host's body and transmission seems to occur normally during direct bodily contact (e.g. mother bird and fledglings in a nest).

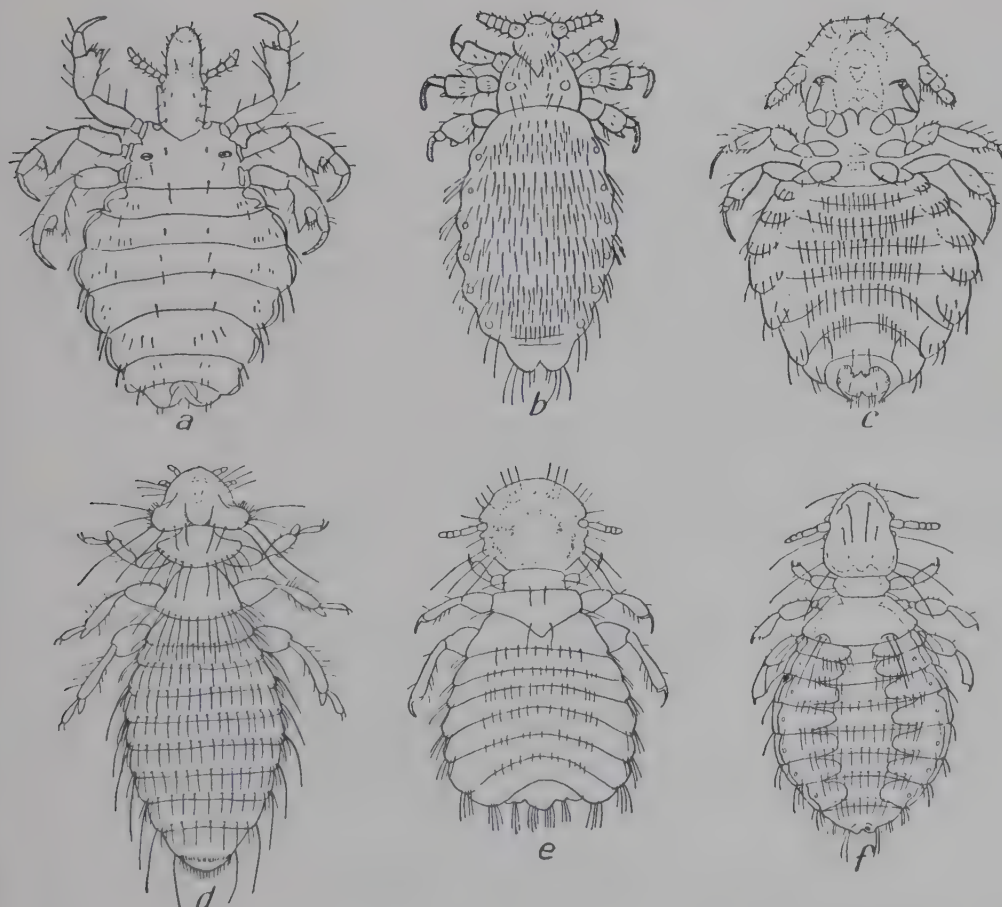


FIG. 26. Sucking and biting lice of animals. (a) *Haematopinus suis*; (b) *Linognathus setosus*; (c) *Trichodectes canis*; (d) *Menopon gallinae*; (e) *Goniodes gigas*; (f) *Lipeurus heterographus*. (After Séguy (1944) *Faune de France* No. 43.) All ♀ except (e). (a)  $\times 8$ ; (b) (c) (d) & (f)  $\times 23$ ; (e)  $\times 14$ .

The following are the most common parasites of some domestic animals:

(i) *On poultry*

*Menopon gallinae* (Fig. 26d) and *M. pallidulum*, *Goniodes dissimilis*, *G. gallinae* and *G. gigas* (Fig. 26e). *Lipeurus heterographus* (Fig. 26f) and *L. caponis*.

Domestic poultry are quite frequently infested with biting lice. The 'dust-baths' taken by fowls and other birds are apparently taken largely to destroy these parasites. When birds become badly infested, bare areas of skin may be seen where the feathers have been eaten through and have fallen out. The presence of numerous parasites causes considerable irritation which disturbs feeding and rest, and results in a very poor condition of health.

(ii) *On dogs*

*Trichodectes canis* (Fig. 26c) occurs on dogs. Unlike *Linognathus* it commonly infests the head and neck.

(iii) *On horses*

*Trichodectes equi* and *T. pilosus*.

(iv) *On cattle*

*Trichodectes bovis* often heavily infests cattle on the withers, root of the tail, neck and shoulders.

### (c) Control of lice of domestic animals

The simplest effective method of destroying these parasites is to apply a finely powdered insecticide to the roots of their fur or feathers. Any of the preparations recommended for use against animal fleas could be employed in the same way. For treating a large flock of turkeys or hens, the following rapid method could be tried. An agricultural dusting machine which emits jets of dust at intervals along an arm is laid on the ground, so that the jets point upwards and towards the flock. The birds are then driven through the dust cloud.<sup>(18)</sup>

Treatments for lice of domestic animals do not require the same degree of attention to kennels, pens, etc., since the immature stages do not live away from the host.

## B · Parasitic and harmful Acari

In Britain, there is only one important acarine parasite of man; that is *Sarcoptes scabiei*, the itch mite. But a number of other mites and ticks may become temporary or accidental parasites and give rise to more or less unpleasant symptoms. A considerable number may be encountered as parasites of domestic animals.

### (A) Human parasites

#### I · THE ITCH MITE (*Sarcoptes scabiei*)<sup>(21, 41)</sup>

Mites of the family Sarcoptidae live parasitically on or in the skins of mammals and birds. The most important, *Sarcoptes scabiei*, infests man; but nearly identical

mites can be found in the skins of various domestic and wild animals. People who (perhaps by reason of their occupation) have intimate contact with animals which are infected, may sometimes acquire transitory infestations from them; but these mites from animals are unable to lodge permanently on man. It seems that, in spite of their very similar appearance and life history, they have physiological idiosyncrasies adapting them to life on particular hosts. Analogous cases are met with among insects, the various strains being known as 'biological races'. On the grounds of small anatomical differences between them, the races of *Sarcoptes scabiei* are classed as varieties, as var. *hominis*, var. *equi*, etc.

#### (a) **Historical**<sup>(21)</sup>

The itch mite and the disease it causes have interesting histories. The association between the two was conjectured in early times, but remained a matter of controversy until about the middle of the nineteenth century.

In ancient times and in the Middle Ages, the mite was considered to be a preliminary stage of the louse. This view was propounded by Aristotle, who considered that lice were generated in the skin; he states that the early stages of lice in the flesh can be pricked out with a needle. In the sixteenth century there are scattered references to itch mites and for the first time it was recognized that they were distinct from lice. Mouffet (see p. 14), for example, refers them to the group Acari, the smallest indivisible form of animal life. He observed that 'Wheale wormes' were to be found on scabetic individuals but did not suggest that they actually caused the disease. In the seventeenth century two Italians, Bonome and Cestoni, first advanced the theory that scabies was due to the mite and their views were supported and spread by an English physician Richard Mead. This view was accepted by many notable doctors and biologists of the eighteenth century, including Linnaeus (who, however, believed *Sarcoptes* to be identical with the flour mite). The first proof of the relationship was made experimentally by Wichmann about 1790; but curiously enough there followed an era of controversy and actual disbelief in the existence of scabies mites. This was largely due to a lack of precision of the earlier writers in describing how to find the mites. Advanced cases of scabies usually display vesicular skin reactions of an allergic nature and often, as remarked above, secondary infections. The mites are very rarely found in these secondary lesions; in fact they are often quite rare at the more spectacular stage of the disease. However, in 1834 the mite was proved to be present in all cases of scabies by Renucci in Paris and shortly afterwards the experimental proof of causation was repeated by Gras.

#### (b) **Life history**<sup>(14, 21, 41)</sup>

##### (i) *Oviposition*

The mature female is the largest form of the scabies mite and decidedly the easiest to demonstrate. She forms meandering burrows in the horny layer of the skin which can be recognized with a little practice. These burrows are much more common on certain parts of the body than others. The examination of a considerable number of patients gave the following figures of distribution:<sup>(4, 27)</sup>

Site	Percentage of mites found in	
	Men (886 cases)	Women (119 cases)
Hands and wrists (excluding palms)	63.1	74.3
Palms of hands	—	7.5
Elbows	10.9	5.9
Feet and ankles	9.2	9.8
Penis and scrotum	8.4	—
Buttocks	4.0	1.1
Axillae	2.4	0.9
Knee	0.7	0.3
Navel	0.4	0.1
Chest	0.1	0.1
Breasts	—	0.5
Other sites	0.8	0.5

It will be observed that a high proportion of cases of scabies could be diagnosed by examination of the hands and arms. The sites where the mites burrow are not necessarily areas where the cuticle is thin; in fact the reverse is nearer the truth.

As she proceeds along the burrow the female lays her eggs.

#### (ii) *Egg*

The egg of the itch mite is smooth, whitish and glossy, its dimensions, when laid, are about  $0.17 \times 0.09$  mm and it increases slightly during development; this size is relatively large compared to the fully grown female which is only about  $0.36 \times 0.26$  mm. When burrows are probed with a needle to extricate the female mites (see p. 263), eggs are sometimes removed adhering to the needle.

#### (iii) *Larva*

The first stage, which emerges from the egg, is known as the 'larva'. This resembles the later stages in general appearance, but is exceptional in having only three pairs of legs, whereas the older mites have four pairs. The two anterior pairs of legs bear suckers and the last pair end with a bristle.

Sometimes newly hatched larvae may be found inside a burrow and they may make some attempt to dig into the floor. Normally, however, they soon emerge and burrow into the skin nearby; or else they may descend into hair follicles. Eventually they moult to form the first nymphal stage.

#### (iv) *Nymph*

The 'nymphs' are stages with four pairs of legs like the adults; both the hind pairs terminate in bristles. The nymphs may be found in short burrows or in hair follicles, like the larvae. Apparently the immature stages spend most of their time in such retreats, but they sometimes come out and travel to new sites.

After a certain time, the nymphs moult again to produce *either an adult male or a second-stage nymph*. The latter undergoes yet another moult before the adult female emerges.

#### (v) *Adults*

The adults are shown in Fig. 27. The females are considerably larger, especially after fertilization, when they reach a size about double that of the males. Like the

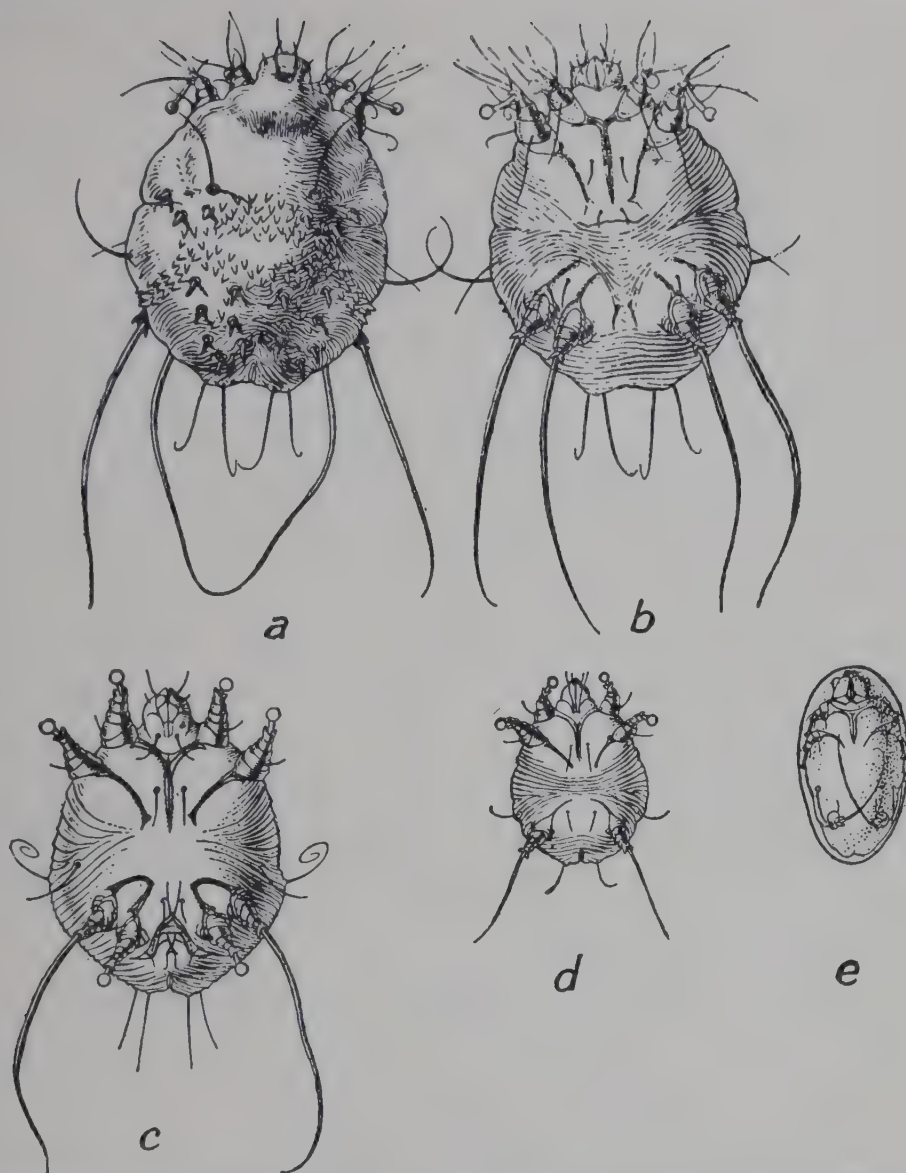


FIG. 27. *Sarcoptes scabiei*. (a) adult female (dorsal view); (b) the same (ventral view); (c) adult male (ventral); (d) larva (ventral); (e) mature egg. From K. Mellanby (1943) *Scabies*, Oxford Univ. Press. (a) & (b)  $\times 100$ ; (c) (d) (e)  $\times 125$ .

nymphs, their two hind pairs of legs bear bristles; whereas the last pair of legs of the male bears suckers.

The 'head' which is broadly attached to the body, bears a pair of toothed 'chelicerae' (see p. 33) like insect mandibles and a pair of short palps; there are no eyes or other organs of the higher senses. The food apparently consists of the horny part of the human skin and, perhaps, certain secretions in the hair follicles (for the younger stage).

The body of the mite has a shape somewhat like that of a tortoise, rounded above and flattened below. The skin is whitish and covered with striations. On the ventral surface can be seen thickened bars in the cuticle to give support for the articulation of the legs. The short stumpy legs appear to be only capable of limited movements; nevertheless, the mites can walk fairly well over flat surfaces with the aid of the

sucker-bearing legs. An adult female travels over the skin at the rate of about 2.5 cm (an inch) per minute.

All stages of the mite show a great inclination to burrow into the epidermis shortly after being placed on the skin. They usually seek out furrows or cracks in the skin and begin to dig in them immediately. The creatures use their jaws and the front two pairs of legs for digging. The latter grip with their suckers and tear at the skin with a cutting edge on the last joint so that the animal gives the appearance of digging with its 'elbows'. The bristle-bearing legs may be used to afford purchase or leverage during the digging operations. On the back of the mite are numerous spines and small projections, directed backward; these may serve to anchor the body in position in the burrow when necessary. Different stages of the mite take from 15 minutes to an hour to bury themselves in the skin. The immature stages and the adult males make only short burrows, whereas the females, after fertilization, form the long meandering burrows already mentioned as characteristic of a scabies infection. The speed at which these burrows advance is very variable, sometimes the animal progresses as much as 5 mm in a day and at other times she only moves about half a millimetre. The adult males are the most active forms of the mite and often leave their small temporary burrows seeking the females.

The sexual organ of the male is ventral while the copulatory orifice of the female is dorsal. When the male enters a burrow containing a virgin female, coition is effected by the male assuming a position facing in the opposite direction to the female; then he tilts his body until his posterior under surface rests on her back end. Copulation may occupy only a few minutes, after which the male leaves the female, and apparently does not mate again.

The female has a separate oviduct leading to an egg pore on the ventral surface of the body. Eggs are laid at intervals along the burrow and remain there until they are hatched.

### (c) Quantitative bionomics

#### (i) *Life history on the host*

The itch mite, which spends most of its time buried in the skin, is even less subject to vagaries of climate than the louse. Consequently it is possible to give single estimates for periods in the life history, under the average conditions of the human skin. These figures are the most reliable modern observations of a life history difficult to trace with accuracy.<sup>(21)</sup>

Egg stage	3-4 days	} <i>Female mite:</i> Total, 14-17 days
Larval stage	3 "	
First nymphal stage	3-4 "	
Second nymphal stage	3-4 "	
Unfertilized adult	?	
Maturation after copulation, before oviposition	2 "	

The male mite lacks the second nymphal stage, so that its development will last only 9 to 11 days.

The life of the adult female has not been followed through, but it seems probable that she lays rather more than two eggs daily. This apparently continues for one or two months.<sup>(21)</sup>

A high proportion of the eggs of *Sarcoptes* hatch; probably about 90%. During development, however, there is a high mortality so that, even under favourable conditions for the mite, only about 10% or less reach maturity.

(ii) *Survival and behaviour away from the host*<sup>(44)</sup>

Adult female mites removed from the host's skin will walk about fairly rapidly at temperatures above 20°C (68°F). They can climb up polished surfaces such as glass without difficulty. They show no reactions to light, either positive or negative, but they show some tendency to walk from cooler zones to warmer ones.

Little movement occurs below 20°C, and at 15°C (59°F) they fall into a chill coma.

*Sarcoptes*, like *Cimex*, survives best at about 13°C (55°F). Given moist conditions (90% R.H.) about 50% may survive for one week and 5% for two weeks at this temperature. Warm dry air is soon fatal; no mites have survived an exposure of two days at 28°C (82°F) and most of them die within 24 hours.

The mites are also killed quite easily by short exposures to higher temperatures. A temperature of 49°C (120°F) appears to be fatal in 10 minutes and 47.5°C (117.5°F) in 30 minutes.

(d) **Parasitology of scabies**

(i) *Transmission*<sup>(38, 42)</sup>

The high mortality of the younger stages of the mite make it fairly certain that only the ovigerous females are normally successful in colonizing a new host. Artificial infestation has been done on many occasions by transplanting an adult female, but attempts with the younger stages have failed. Once the adult female has formed her burrow on the new host, she goes on producing progeny regularly and usually sufficient survive to set up a new infestation.

The helplessness of *Sarcoptes* away from the host at temperate room temperatures and its poor powers of survival under warmer conditions, greatly impair its chances of indirect infestation by fomites, etc. This has been substantiated by experimental evidence and by the questioning of infected patients. It is clear that the great majority of sufferers acquire scabies by intimate association with an infested person, usually by sleeping in the same bed with them. Scabies has acquired some opprobrium as a 'venereal complaint'; but its best chances of spreading are by the regular contacts of marriage and family life (e.g. where children sleep together or with their mother). Therefore it is more reasonable to regard it as a familial infection. There is an unknown amount of infection by more transitory contacts, as between children at play or hand-holding or caresses of adults at dances, cinemas, etc. Finally there is a small percentage of cases due to infection by fomites. (An

indication of the frequency is given by 300 experiments in which bedding used less than 24 hours previously by a scabetic patient was slept in by an uninfected volunteer. Transmission occurred in four cases only. With very high parasitic rates the chances were considerably increased; but such infestations are rare.)

(ii) *Population growth*<sup>(42)</sup>

Estimates of populations of *Sarcoptes* and their growth and decline must be made by counts of the ovigerous females. Other stages are difficult to find, and it is not possible to determine how many of them are present on an infested individual. However, the number of females can be determined with some accuracy by a careful examination of the patient's body; and this serves as an indication of the magnitude of the total mite population.

If the numbers of progeny of a single fertilized female are estimated according to the life history data, assuming no mortality during development, it can be calculated that about 100 adult mites would be present after one month and several thousands after two months. Large numbers are very rarely encountered in actual infestations. A series of 886 scabetic recruits examined during World War II were found to carry 9978 mites, an average of only 11.3 per man. Over half the patients had under 6 mites and only 3.6% had over 50.<sup>(27)</sup> It is clear that there is some drastic check to population growth.

The growth of mite populations in the human skin has been studied by artificially infesting volunteers. These experiments were abnormal in one respect, for these volunteers did not resort to self-medication, which common practice has a drastic but rarely exterminating effect upon many natural infestations. It was observed that the progress of the mite community in a person infested for the first time was very different from that in reinfested individuals. The reason for this is that the human skin becomes sensitized to the presence of the parasites and sets up an acute reaction inimical to them.

In an original infestation (by a single ovigerous female) the second-generation adult females begin to appear after three or four weeks. During this period, the presence of the mite and her progeny causes no symptoms. Thereafter, the population grows, slowly at first and later at a faster rate, for about two months. At the beginning of this period, sensitization occurs and there follows a gradually increasing skin reaction which is accompanied by more and more severe irritation. The reaction of the skin, which is characterized by erythema and the formation of small vesicles, suppresses the activity of the mites and, in addition, the irritation results in a number of ovigerous females being scratched out of their burrows and destroyed.

About three months after the original infestation, when there may be a few hundred female mites present, the reactions of the host become so intense that the mite population begins to decline sharply. It was not possible to study the further course of infestations in the volunteers because, at this point, all of them were suffering severely from secondary infections. It seems likely that a small fluctuating residual mite population would remain for some time, and sometimes, perhaps, die out spontaneously.

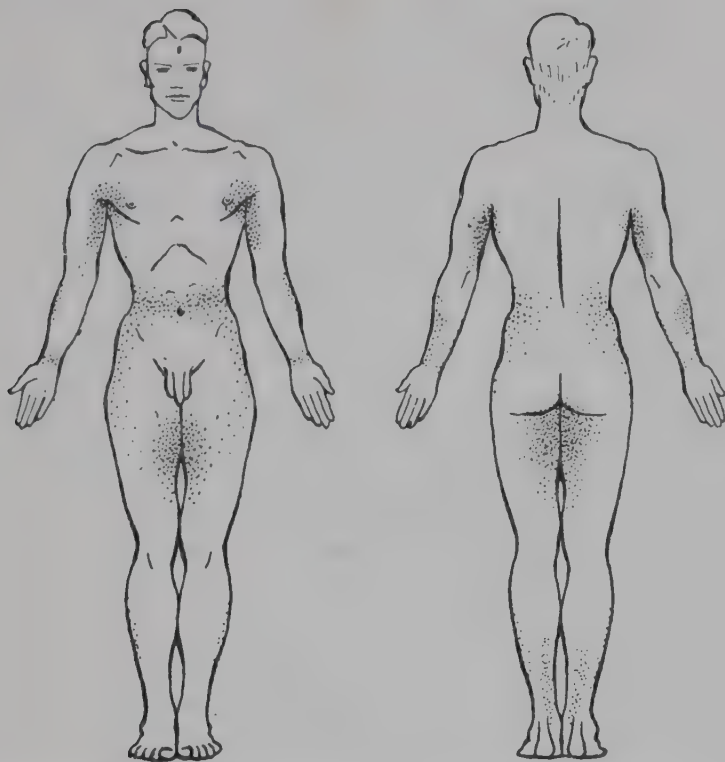


FIG. 28. *Scabies* 'rash'. (N.B. the rash does *not* correspond with the sites of election of the mites.) From Mellanby (loc. cit.).

The course of an infestation in a person who has suffered from scabies before is very different. Such a person will have been sensitized to the presence of the mites, provided that he has been infested for several months. (Though sensitization begins after a month, it is only fully developed after about six months.)

In the first place, it is very difficult to reinfest sensitized people. The skin reacts strongly within a day or so of implantation of an ovigerous female, and the surrounding area becomes intensely itchy. Even if a mite colony is established, the number of parasites never reach very high figures (usually less than 25). Quite often these infestations die out spontaneously. To some extent, therefore, infestation by *Sarcoptes* results in a partial immunity, apparently due to an antibody function.

The course of an infestation in an ordinary citizen is complicated in most cases by the use of medicaments as soon as the irritation begins (about a month after infestation). These substances, sometimes ineffective and often improperly applied, usually reduce the population of mites to a moderate, fluctuating figure. Sensitization continues to develop and the mites either remain at a low density for months (or years) or else die out. It will be appreciated that where the population of ovigerous females is as low as a dozen or so, the number destroyed by scratching may be decisive.

#### (e) Importance

The reactions of various hosts to infestation by *Sarcoptes* are quite different. In animals, large numbers of the parasites give rise to sarcoptic mange; in man they

cause the quite different disease known as scabies, in which unpleasant symptoms may be due to relatively small numbers of the mites.

At a certain stage, the infestation of the human skin by the itch mite gives rise to more or less severe irritation. This causes the sufferer to scratch himself vigorously and, very commonly, to resort to widely advertised 'skin trouble' ointments. The constant scratching is liable to break the skin and allow the entry of micro-organisms. Pustules, boils, ecthymata, impetigo or eczema may result, which, if neglected, will require prolonged medical treatment. Attempts at self-medication are, for several reasons, seldom successful; and they may give rise to severe dermatitis, if such things as sulphur ointment are used too frequently.

Scabies then is a distressing affliction often attended by unpleasant sequelae. Though it is commonly associated with a lack of cleanliness, there is certainly no direct causal relationship, for a scabetic infestation will persist in a scrupulously clean person. Furthermore, no evidence has been found among samples of recruits to the army that the sufferers from scabies were less intelligent than normal.<sup>(39)</sup>

It is difficult to compare the prevalence of the disease today with its occurrence in earlier times owing to former uncertainties in diagnosis and confusion with other skin complaints. Figures for the present century show a rise during the war of 1914-18 followed by a decline and another rise beginning a few years before the Second World War. By 1941 the incidence had risen until certain hospitals in urban areas recorded 2.5 to 4.0% of patients as suffering from scabies when admitted for other diseases.<sup>(37)</sup> On these data it was suggested that the general average among the British population might not be very much below 2%. According to some figures based on examination of over 20,000 school children annually, the rate in a northern city fell from about 0.82% in 1944 to 0.18% in 1947. In two other British cities, the decline continued till 1953 and 1957 respectively; but in more recent years, there was evidence of a slight recrudescence in incidence (see Table 1 p. 10). Girls were more often infested than boys. It is generally agreed that the more severe forms of the disease, due to long neglect, are becoming rarer.

## (f) **Diagnosis and cure of scabies**

### (i) *Diagnosis*

It is difficult or impossible to discover a primary case of scabies in the first three or four weeks after infestation, before sensitization has developed. Thereafter, a typical case is fairly easy to recognize, in the absence of complications (i.e. secondary skin infestations). The patient complains of severe irritation which becomes intolerable at night, often preventing sleep. An examination of the body reveals a rash of follicular papules, characteristically developed in certain parts of the body as shown in Fig. 28. This rash is apparently due to a sensitization to the mite, aggravated by the patient's scratching. It is important to remember that the rash does *not* correspond to the sites selected by the mature females to form their burrows. In the latter regions, the burrows can often be distinguished as tiny meandering greyish-white tunnels, often broken open by scratching. Around them may be found vesicles about the size of wheat grains. Small crops of these vesicles may

sometimes be found in other sites, unconnected with the burrows; they often occur on the hands or feet of small children, for example.

A person who has suffered from scabies before, for a sufficient time to develop sensitization, responds quite differently to a second infestation. Local reactions (erythema and oedema) occur within a day or so in the region where an invading female has burrowed. Often the unfavourable skin reaction and the scratching of the sensitized host are sufficient to exterminate a secondary infestation. However, where a sensitized person is being repeatedly reinfested (e.g. by regularly sleeping with an infested individual) a fresh infestation may become established. When this happens, general signs and symptoms of scabies usually develop all over the body in about a week or so.

Owing to the constant scratching induced in the later stages of scabies, secondary skin infections are common. Conditions such as ecthymata, impetigo or eczema may obscure the typical signs of scabies. The mites will not develop in close proximity to septic lesions and, in any case, they are usually scarce in advanced scabies. Nevertheless, it is important to diagnose scabies, since the irritation, and hence the liability to skin diseases, cannot clear up until the parasites have been extirpated.

*The best proof of scabies* is to extract and demonstrate the adult female mite. (If the patient is shown the creature under a microscope, it will ensure his co-operation.) Extraction of the mites is not difficult. First, the burrow of a mature female is sought in the most likely spots (e.g. between the knuckles, in folds of the wrist and elbow, etc.). Then the burrow is gently pricked open, working towards the end where the mite can usually be distinguished as a dull white spot. In this way, it is usually possible to extract the mite undamaged and adhering to the needle. A watchmaker's eyeglass is useful for the operation; it leaves the hands free.

## (ii) *Treatment*<sup>(43, 45)</sup>

### 1. *Bathing*

Scabies can be cured without bathing, but since many patients are somewhat dirty, a bath before treatment is desirable for hygienic reasons, and necessary where secondary skin infections are present. Scrubbing, which was formerly considered essential, is unnecessary.

### 2. *Medication*

A mite-killing substance is applied to the whole surface of the body, excluding the head. Thorough treatment is essential and is best done by a reliable nurse or orderly, though sometimes it may be possible for the patient to be properly treated at home. Ointments may be rubbed on by hand and liquid preparations are best painted on with a soft flat paintbrush about 2 inches wide. After treatment with an ointment, the patient can dress at once. The more greasy ointments tend to soil the underwear somewhat, and could, perhaps, be improved by using a 'vanishing cream' type of base. After treatment with an emulsion (e.g. benzyl benzoate) the body is allowed to dry for 5 or 10 minutes in a warm room. Whatever the treatment, the patient is instructed not to take a bath for at least 24 hours.

Of a considerable number of substances used for treatment, four appear to be most reliable.

*Sulphur ointment B.P.*, which contains 10% sulphur in a Vaseline base.

*Marcussen's ointment*, a mixture of unstable polysulphides.

*Benzyl benzoate*, may be used in various forms, of which emulsions are perhaps preferable. One good formula is as follows: benzyl benzoate 250 ml, lanette wax S.X. 20 gm, water 750 ml.

*Dimethyl-diphenylene disulphide (Dimethyl-thianthrene)*, a yellow oily liquid which can be used undiluted, but has given good results in dilutions down to 10% in medicinal paraffin. This substance has rather fallen out of use owing to scarcity during the last war.

The following substances have been found unreliable at concentrations feasible in practice: flowers of sulphur; thiosulphate followed by hydrochloric acid; sulphur soap; derris or rotenone preparations; a pyrethrum preparation; betanaphthol; and 'Lethane'.

A second application of the chosen medicament should be made a few days after the first and in the same week. This is in the nature of a safeguard, since a very high proportion of cases are cured by one treatment.

The patient may complain of continued symptoms even after all mites have been destroyed, for the sensitized skin sometimes remains irritable for a time. Occasionally itching weals may appear periodically for a few weeks after a cure. There is much variation between different individuals and the symptoms appear to be partly nervous in origin.

After the second treatment, however, no further applications should be made, since too frequent use of these medicaments may lead to dermatitis.

### 3. *Sterilization of fomites*

Where facilities exist, the patient's bedding and clothing may be disinfested by heat. However, this is of minor importance compared to efficient medication. Mites are not likely to survive for long in the bedding or clothing used by the infested person and the residue of ointment applied will destroy wandering mites attracted to the skin in the day or so following application.

### 4. *Secondary infections*

These are medical problems strictly beyond the scope of this book. Briefly it may be remarked that mild secondary infections often clear up spontaneously as soon as the scabies is cured. Where further treatment seems necessary it is usual first to remove any scabs and crusts (e.g. by boracic fomentations or poultices) and then treat the underlying sepsis with a dilute mercurial ointment, or by an acriflavine or calamine lotion or by gentian violet. A small proportion of cases may be found refractory and these require the attention of a competent dermatologist.

### (iii) *Prophylaxis*

Since the burrows of the ovigerous females are usually concentrated in the hands and wrists, it might be hoped that regular treatment of these regions might stamp out scabies from a community. A large experiment in which this was tried with

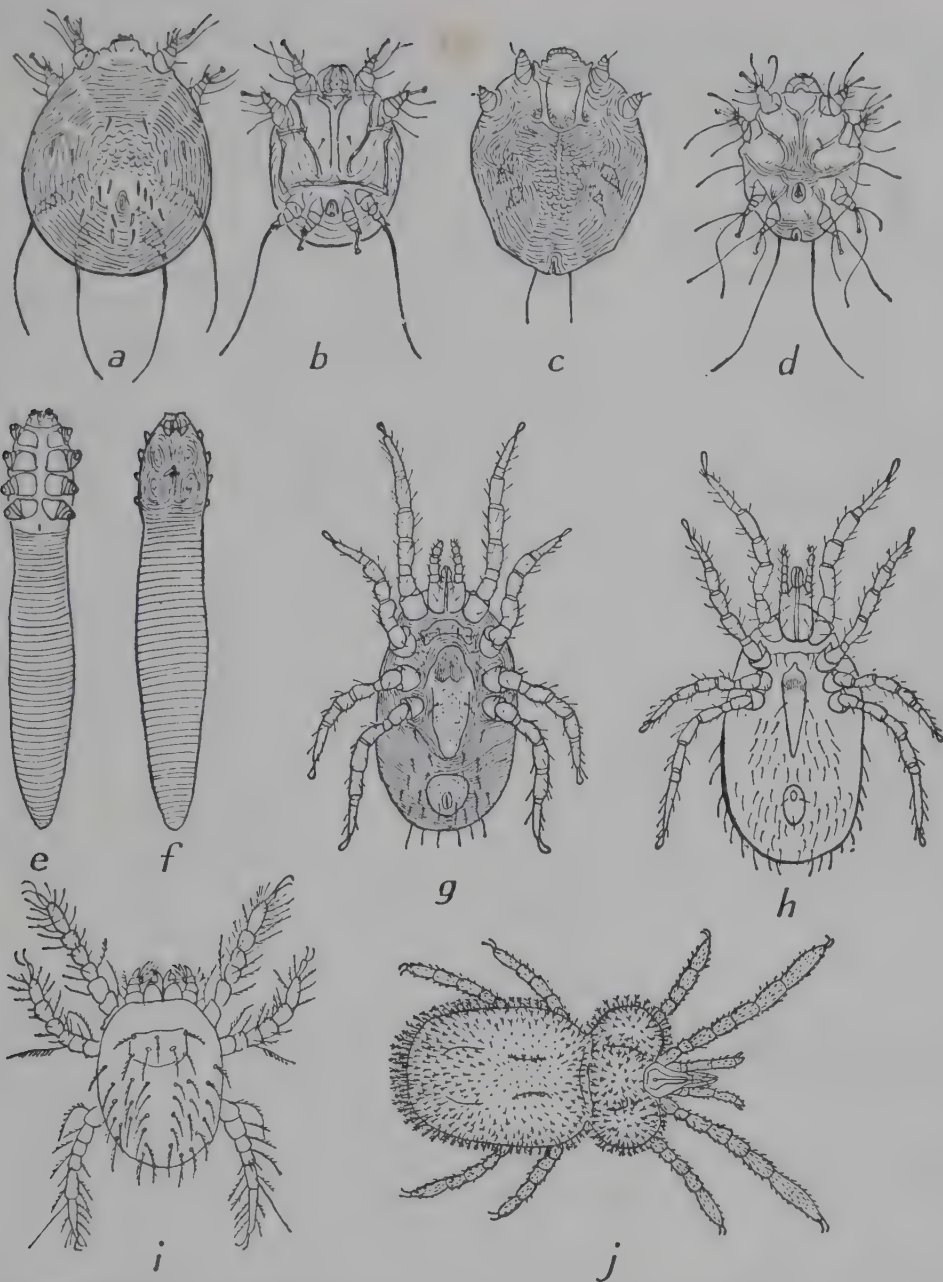


FIG. 29. Parasitic mites. (a) *Notoedres cati* var. *cuniculi* (dorsal, female); (b) the same (ventral, male); (c) *Cnimidocoptes mutans* (dorsal, female); (d) the same (ventral, male); (e) *Demodex folliculorum* (ventral, female); (f) the same (dorsal, male); (g) *Dermanyssus gallinae* (ventral); (h) *Ornithonyssus bacoti* (ventral); (i) larva of *Trombicula autumnalis*; (j) adult of same. (a) to (h) after Hirst, *Mites injurious to man and to domestic animals*, Brit. Mus. (Nat. Hist.). (i) & (j) after Finnegan, *Acari*, *ibid.*, (Econ. Series No. 16). (a) & (b)  $\times 100$ ; (c) & (d)  $\times 60$ ; (e) & (f)  $\times 150$ ; (g) & (h)  $\times 40$ ; (i)  $\times 100$ ; (j)  $\times 20$ .

school children, however, failed to show very much better results than in the control groups.<sup>(45)</sup> The results indicated that regular inspection (and treatment where necessary) has a beneficial effect, and this has been confirmed elsewhere.

A similar type of prophylaxis, which has given excellent results among a closed community (in an institution), is to issue soap containing 5% of the substance tetraethylthiuram monosulphide ('tetmos') in the place of ordinary soap.<sup>(19)</sup> This

cured almost all the sufferers in about 13 weeks and there were no signs of dermatitis in the 400 persons using the soap for that period.<sup>(5)</sup>

## II · THE FOLLICLE MITE (*Demodex folliculorum*)

Like others of its group, this mite has a curious body form (Figs. 29e, f); the long striated abdomen giving a somewhat worm-like appearance. It is a small mite (less than 0.4 mm long) and, though often present in human sebaceous glands, it usually escapes notice. These mites may be sometimes found if the contents of a 'black-head' are squeezed out and examined under the microscope. There is, however, no evidence to show that blackheads are caused by the mites which appear to be quite harmless, in most cases. On rare occasions, however, it appears that the mites are associated with a rash of tiny red follicular papules on the face or scalp. In such cases, an ointment containing 10% sulphur and 5% balsam of Peru was found to be an effective cure.

Other species of *Demodex* occur in domestic animals, and cause manges of a more or less severe type (see p. 268).

*Life history.* Very little is known. The eggs, which are heart-shaped, give rise to larvae with three pairs of legs. There are probably two nymphal stages, both with eight legs. These young stages vary considerably in size.

In the adults, the sexes can be distinguished by the penis of the male which protrudes dorsally at the level of the second pair of legs. In the female, the genital orifice is a ventral slit between the last pair of legs.

## (B) Animal parasites, sometimes attacking man

### I · MANGE MITES

A considerable number of mites of the family Sarcoptidae live parasitically on the skins of various domestic animals and birds. Some of them live on the surface of the skin and cause superficial irritation; others enter the skin or its glands and cause the conditions known as mange or scab. The most important genera are *Psoroptes*, *Sarcoptes*, *Notoedres*, *Cnemidocoptes* and *Otodectes*.

As mentioned in connection with *Sarcoptes scabiei*, most of the species concerned have a number of varieties which are very similar or identical in appearance, but which are physiologically adapted to living on different hosts. Thus it is very difficult, or impossible, to infest a different kind of animal with one of these mites.

#### (a) Species concerned

##### (i) *Sarcoptes scabiei*

A variety of this mite causes sarcoptic mange in dogs, a contagious infection which may give rise to transitory human infestations. It is an unpleasant disease but, fortunately, very easy to cure, in contrast to demodetic mange (p. 268). Usually the disease appears first round the eyes, outside the flaps of the ears, on the elbows,

hocks or abdomen; thereafter it may spread all over the dog unless checked. The affected areas become bare and covered with small spots, like fleabites. The mite causes irritation and the scratching of the dog causes numerous small scabs and sores to develop.

*Sarcoptes* causes a mange in rabbits; the nose being mainly attacked and becoming thickened and enlarged. From the nose, the mange may spread over the face and ears and sometimes to the body. A serious and sometimes fatal condition results if the parasite is not checked.

Sarcoptic mange in horses, though relatively rare, is an unpleasant complaint which causes intense itching. The signs are little round hairless patches and small elevations which can be felt if the hand is passed over the skin. The withers are usually affected first and the disease spreads along the back and sides.

(ii) *Notoedres cati* (Fig. 29a & b)

The genus *Notoedres* is closely related to *Sarcoptes*, the two mites being very similar in form. This mite is responsible for a mange in cats. The attack generally starts on the neck and afterwards spreads over the head. Greyish crusts are produced and finally the whole affected skin becomes leathery.

Another variety of *N. cati* (var. *cuniculi*) cause a type of mange in rabbits; and yet another species *N. muris* attacks rats.

(iii) *Psoroptes communis*

This non-burrowing form occurs on the following domesticated animals: rabbits, horses, sheep, goats and cattle.

People who keep tame rabbits are sometimes troubled to find infestations of *Psoroptes communis* var. *cuniculi* which mainly attacks the ear. The presence of the mites produces a yellowish substance, consisting mainly of dead flakes of epidermis, which may practically fill up the auditory meatus. This disease does not seem to be very infectious, for it often does not spread from mother to young or from one ear to another.

(iv) *Cnemidocoptes mutans* (Fig. 29c & d)

This mite causes 'scaley leg' in poultry; it proliferates under the scales of the legs and causes a serous exudate, which may become very thick and nodular. A related species (*Cn. laevis* var. *gallinae*) causes 'depluming itch'. It lives in the skin at the base of the feathers and causes irritation. The bird plucks at the feathers which become broken until often only the midrib is left.

(v) *Otodectes cyanotis*

Mites of this species live in the ears of dogs, cats and ferrets. *O. cyanotis* var. *felis* is fairly common in cats, and the otitis caused by it is generally known as 'canker'.

(vi) *Demodex*

While *Demodex* does not belong to the Sarcoptidae, it is mentioned here because it produces mange in domestic animals.

*Demodex canis* causes a severe and highly unpleasant mange in dogs, which is very difficult to cure. It gives rise to variable clinical signs and the condition may be complicated by a bacterial infection. Usually, small patches of bare skin appear on various parts of the body; later pimples and pustules develop, and finally secondary infections are liable to produce running sores accompanied by a disgusting odour. The disease is, fortunately, not very infectious.

(vii) *Miscellaneous mites*

A number of other mites occur among fur or feathers, not necessarily causing any injury. Some of them are known to be predatory on harmful mites.

(b) **Control of mange mites**

It will be appreciated that the whole life cycle of these mites is passed on or in the epidermis of their host. The biology of many of them is not known in detail, but it appears most unlikely that any of them can survive for a long time away from the host. Some of the infestations are of very low infestivity and it is not known how the mites spread. Most varieties are specific parasites of one type of host though transitory infections on other animals may occur; on people, for example, who continually handle infested animals.

Control measures consist in skin treatments, either local or general, according to the severity of the disease. In some cases it may be advisable to remove exudate or crusts to allow the medicaments access to the skin.

The lesions should be treated with (i) sulphur ointment (which is successful in relatively bare places) or (ii) benzyl benzoate ointment (p. 264) applied with a brush or (iii) 'Tetmosol' solution or emulsion (a preparation of tetra ethyl thiuram monosulphide, made by Messrs I.C.I. Ltd).

For treatment of fowls attacked by depluming mite, dipping the whole bird in a sulphur bath ( $\frac{1}{2}\%$  soap, 2% finely ground sulphur) is commonly used.

## II. THE HARVEST MITE (*Trombicula autumnalis*)

(a) **Characteristic appearance**

The adult mites of the family Trombididae may be recognized fairly easily from their velvety appearance (due to a coating of stiff serrated bristles) and the central constriction, giving them the shape of a figure 8 (Fig. 29j). Many of them are bright red or orange in colour and are readily noticed when abundant.

Whereas the adults live a (to man) harmless predatory or scavenging life, the larvae are parasitic on vertebrates and sometimes attack humans. The six-legged larvae are only about 0.2 to 0.3 mm long, red to pale yellow in colour and bearing numerous feathered setae (Fig. 29i). A considerable number of larval forms of these mites are known from different parts of the world and they are assigned to six genera. One species, *Trombicula autumnalis*, is known as the 'Harvest mite' in Britain, 'bete rouge' or 'aoutat' in France, 'Herbstgrasmilbe' in Germany, etc.

### (b) Distribution

*T. autumnalis* occurs over most of northern Europe. In any country its distribution is rather patchy, for unknown reasons. In Britain, for example, chalk downs are particularly liable to heavy mite populations.

### (c) Life history

The females lay their eggs in the soil. The eggs (100–200  $\mu$  long) finally hatch to produce the six-legged larvae. These young larvae climb up herbage to the tips of leaves to await an opportunity of attaching themselves to a vertebrate host. Various rodents are commonly attacked, especially rabbits; but the mites have been found on a number of other animals and birds.

Having reached a host, the mites find their way to a suitable area and insert their mouthparts and remain attached for several days. They are commonly found in the ears and around the genitalia of small mammals; on the thighs, under the wings and around the anus of birds. On man, the mites usually crawl up until they reach a constriction of clothing (garter; waistband) and then attach themselves. The secretion of the mite's salivary glands evokes a reaction from the host resulting in histolysis with peripheral hardening; thus a tube is formed, up which the mite can suck lymph (not blood). Finally, the larvae drop off to the soil and eventually moult to produce a non-parasitic eight-legged nymph. This in turn gives rise to the adult which, like the nymph, appears to live on the eggs and young of small arthropods. Thus the mites only attack a single vertebrate host during their life cycle; this attack occurs in the larval stage.

### (d) Quantitative bionomics

The duration of the post-larval stages vary considerably according to temperature, humidity and the availability of food. The entire cycle may require from two to twelve months or even longer. One to three generations a year are thought to occur.

### (e) Importance

In large parts of eastern Asia, mites of the genus *Trombicula* are vectors of the Rickettsia which causes scrub typhus.

In Britain the harvest mite is merely a nuisance; but it can be a severe one from the intense and prolonged irritation caused by its bites. Rural workers or picnickers are liable to be attacked; in fact, anyone who sits or lies on infested ground in summer or autumn. A line of weals is often formed where the mites have bitten along the line of a constriction of clothing.

### (f) Control

At the present stage of knowledge, prevention of the bites is much simpler than destruction of the mites. The usual routes of attack of the mites on low herbage are over socks or stockings and up the legs. Agricultural workers, picnickers, etc., may expose other parts of the body when sitting or lying on the ground. The larva is so small that it readily penetrates through many forms of fabric; through socks and stockings, for example. However, it can be easily checked by rubbing the socks or

stockings several times between hands moistened with a repellent. Cuffs, necklines and other openings of the clothes may be given this 'barrier' treatment, which is quite invisible on most materials. Dimethyl phthalate or benzyl benzoate (both undiluted) are equally effective. Garments treated in this way will afford protection for about a fortnight.

### III · BLOODSUCKING MITES

Mites of the family Dermanyssidae have a rather characteristic shape (see Fig. 29g, h) with plates on the dorsal and ventral sides. They are medium-sized mites moderately covered with short bristles. Certain forms are parasitic on vertebrates and occasionally suck the blood of man.

#### (a) **The red poultry mite, *Dermanyssus gallinae*** (Fig. 29g)

This mite is a common parasite of wild birds in temperate climates, but it also thrives in poultry houses, giving rise to the common name. The adult is about 1 mm long and the red colour mentioned in the name is due to the blood visible soon after a meal. Later, however, the partly digested blood turns black.

#### *Life history*

The females lay batches of up to 7 eggs 1 to 2 days after a blood meal. The eggs (about 0.4 mm long) are laid in crevices in the vicinity of the host; that is, in a bird's nest or poultry roost. The eggs hatch to produce a six-legged larva, which does not feed but remains quiescent. The larva moults to give an eight-legged nymph which visits the host for a blood meal and then retires to a crevice nearby. Another moult produces the second-stage nymph which again feeds and finally moults to give the adult. The nymphs and adults generally feed at night and remain hidden in crevices during the day. The adults are very resistant to starvation and have survived without a blood meal for 4 or 5 months.

#### *Speed of development*

Under rather hot conditions (27–28°C; 80–83°F) the egg hatches in 1–2 days; the larval stage takes 1 day and the nymphal stages 5 or 6 days. Total development then, occupies 7 or 8 days; but under cooler conditions this is no doubt prolonged.

#### *Importance*

Heavy infestations will severely affect chickens, reducing growth and egg-laying and even causing death. The mites will also attack man and apparently take blood meals, though they will not breed in association with man alone. Many of the complaints of *D. gallinae* are due to infestations of wild birds' nests which have invaded adjacent rooms and annoyed the occupants.

#### *Control*

The source of infestation of houses and offices should be sought in nests in eaves or attics. Such nests should be removed and all adjacent walls sprayed with an acaricide.

cide. Infested poultry houses should be cleared of litter and sprayed. Suitable sprays would be 0.5% gamma BHC or 1% malathion. Alternatively, 2% malathion dust at 1 lb to 20 sq ft could be used in poultry houses.

(b) **Tropical rat mite, *Ornithonyssus bacoti*** (Fig. 29h)

This mite is associated with rats all over the world, in both tropical and temperate climates. It resembles *D. gallinae* in general, but can be distinguished by the shape of both dorsal and ventral plates, the hind end being pointed in *Ornithonyssus* and blunt in *Dermanyssus*. Like *D. gallinae*, this mite is red after a blood meal, but becomes blackish as the blood is digested.

*Life history and development*

The life cycle involves the same stages as *D. gallinae*: egg, six-legged non-feeding larva, two nymphal stages and adults. The feeding habits are also rather similar. In a laboratory colony maintained 'at room temperature', the total length of development varied from 11 to 16 days.

*Importance*

While *O. bacoti* is primarily a parasite of rats, people living or working in rat-infested buildings may be attacked and suffer bites.

*Control*

Rodent control is the best measure to protect humans from bites of the rat mite. Mites which have found their way into living quarters, offices, etc., can be destroyed by the sprays recommended for *D. gallinae*.

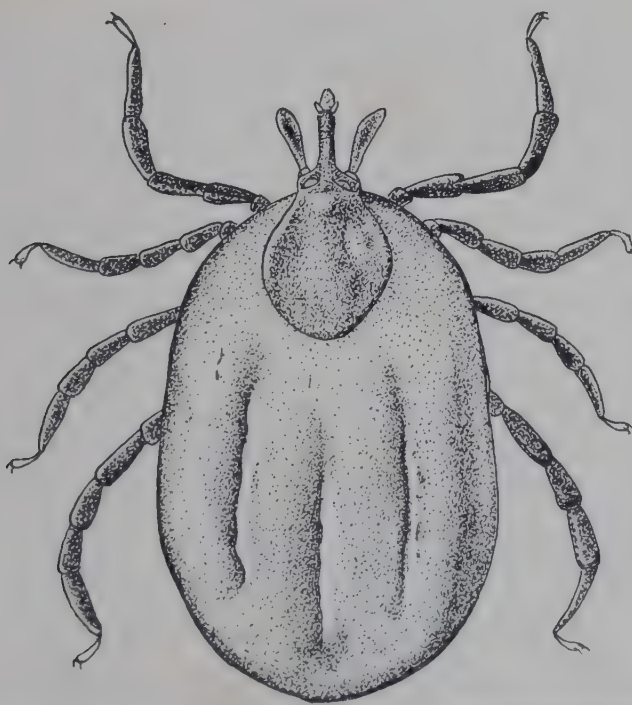


FIG. 30. *Ixodes ricinus* (female). The castor bean tick. (After Hirst, l.c.)  $\times 8$ .

## IV · TICKS

### (a) Distinctive characters

There are two kinds of ticks differing considerably in habits and in appearance so that they are fairly easily distinguished. The Ixodidae or 'hard ticks' are characterized by a hard plate or shield on the anterior region of the back, the remainder of which is smooth. This shield covers the entire back of the male but only a small proportion of that of the female, whose body is capable of great distension after feeding. The mouthparts of ixodids are visible from above, projecting in front of the body. The Argasidae or 'soft ticks' have no dorsal plate and the cuticle is rough and thrown into numerous creases and folds. The mouthparts are under the body and not visible from above.

In Britain, only hard ticks of the genus *Ixodes* are of veterinary or public health importance. They are common parasites of various wild animals but they frequently attack domesticated animals (sheep, cattle, dogs) and sometimes feed on man. The females are most usually noticed, since they attack for long periods (8 or 9 days) and swell up to the size of a pea. The hard parts of the cuticle are brown and the swollen abdomen bluish-grey (Fig. 30).

The two common British species may be distinguished as follows:

Front coxae with a long spine, directed backwards; shield rounded	<i>I. ricinus</i>
Front coxae with only a very short spine; shield lozenge-shaped	<i>I. hexagonus</i>

The castor bean tick, *I. ricinus*, is the more common. It has been extensively studied and the following biological data refer to it (though probably *I. hexagonus* is not greatly different).

### (b) Life history

When the females have taken a meal of blood, they drop off to the ground and after a period of several weeks proceed to lay eggs. The eggs are laid at the roots of grass and among vegetable debris. Each egg is covered with a viscid secretion which prevents desiccation. From the eggs hatch larvae with three pairs of legs. After a resting period, the larvae climb up to the tips of blades of grass or other herbage and, holding on by their hind legs, stretch out their other limbs seeking a host. When they succeed in getting on to a suitable host, they select a suitable spot and embed their mouthparts in the skin. They remain attached, taking a blood meal for 3 to 4 days and then drop off to the ground. Here they retire to chinks and crevices and moult to the next stage which is an eight-legged nymph. The nymph climbs up herbage, and seeks another host in the same way as the larvae. It remains attached for about 5 days and drops off to moult to the adult stage.

The adults seek hosts in the same way as the younger stages but only the females take a prolonged blood meal (8-9 days). The males may attach lightly for a few hours, but their main concern is to find and mate with the females.

### (c) Relation to feeding and environment

Like other ticks, *Ixodes* is very resistant to starvation and, indeed, this is essential in view of its uncertain chances of reaching the host. Unfed larvae have been able

to feed after 15 months' starvation and nymphs after a period of 13 months without a meal. Unfed adults have survived for 21 months. The opportunity of feeding regulates the speed of development which is also, of course, dependent on the temperature.

*Ixodes* is very sensitive to dry air and cannot be reared in the laboratory at humidities below 80–85% R.H. In nature, the greatest danger of water loss occurs when the ticks are seeking hosts at the tips of grass and foliage, and they never attempt to do this in hot weather. Consequently there is a tendency for a seasonal periodicity as follows; the British winter is too cold for development or parasitism. In spring and autumn, with air temperatures of 7–16°C (45–60°F) the ticks make periodic attempts to feed. During the summer months, development proceeds, but there is little or no parasitism.

#### (d) Importance

*Ixodes ricinus* is of considerable veterinary importance, since it transmits the sheep disease known as louping ill and also a cattle infection.

Occasionally these ticks become attached to dogs or to human beings, usually, though not exclusively, in rural areas. The bite of the tick is not serious to man, though it may be alarming on account of the size of the tick and the difficulty of inducing them to relax their hold. If the tick is torn off by force, the body may be pulled away leaving the capitulum (mouthparts) embedded in the flesh. This may lead to irritation and sometimes to septic conditions.

Occasionally the ticks embed themselves in the skin with exceptional firmness and the reaction of the bite stimulates the tissues to proliferate round the tick. This forms a cup-like cyst which may practically cover the tick.

#### (e) Removal of attached ticks

The best method of removing attached ticks is to dab them with chloroform or ether, after which the capitulum should be pressed inwards, to loosen the teeth, and then the tick is gently pulled away. If it is not possible to use a volatile solvent, the tick should be covered with a pledget of cotton wool soaked in medicinal paraffin or olive oil. In this case the removal should not be attempted for some hours after application of the dressing.

### (C) Accidental Parasites

#### I. MITES CAUSING DERMATITIS<sup>(3, 24)</sup>

A kind of 'facultative parasitism' may occur with the mite *Dermatophagoides schereemetewski* (Fig. 31), which appears to be widely distributed in the world. It has been collected from samples of house dust in various parts of Europe, from dwellings where people were suffering from dust allergy.<sup>(61)</sup> Occasionally, it has been recorded as infesting the skin (primarily of the scalp, but also other parts of the body) and causing dermatitis. One case of very persistent infestation was described in detail by the sufferer herself.<sup>(60)</sup> Other instances were concurrent with

infection with a pathogenic fungus.<sup>(3)</sup> *Dermatophagoides* belongs to the family Epidermoptidae, in which other genera occur in the legs of birds, causing scaly skin disease.

A number of mites, which are normally free living, are liable to cause an irritation of the human skin, possibly of an allergic nature. An irritant but transitory dermatitis results, which normally clears up when association with materials infested with the mite ceases. Individuals vary considerably in their sensitivity to these mites, but a considerable proportion are likely to suffer if they have repeated intimate contact with heavily infested materials. Such men as dock labourers, porters and warehouse men are especially prone to attack by reason of their occupation; and these men may carry the mites back to their homes and cause trouble among their families.

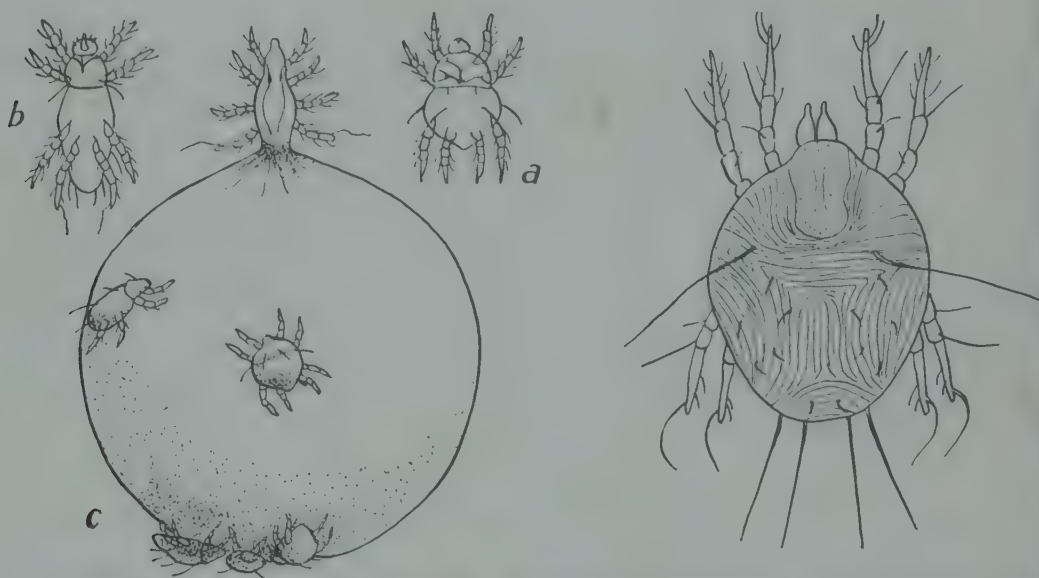


FIG. 31. Mites which can cause skin irritation. Left: *Pyemotes ventricosus*. (a) male; (b) immature female; (c) gravid female, with 5 males crawling over her. (After Vitzthum, *Acarina*, 1931. (a) (b)  $\times 65$ ; (c)  $\times 40$ . Right: *Dermatophagoides schereemetewski*.  $\times 120$ . (After Baker, E. W. and Wharton, G. W., *Acarology*.)

The effects of the attack are urticarial lesions, the individual spots ranging from a few millimetres to over an inch in diameter. Various parts of the body may be affected, but especially the hands, arms and chest. Symptoms of intense irritation are caused and scratching (as usual) may give rise to secondary septicaemia. In severe attacks, there may be pyrexia. It is not clear what causes the trouble since it is unlikely that the mites actually bite the skin; also, severe irritation can be caused by dead mites in large numbers. Possibly an allergic reaction is set up by the mites or their faeces.

### Mites concerned

It is probable that a wide variety of mites associated with stored products can cause dermatitis in people regularly coming in contact with large numbers of them. Perhaps the most common cause is *Pyemotes ventricosus*, the grain itch mite with a

curious life cycle, described on page 333. As it is parasitic on various insect larvae occurring in stored products, it has been reported in association with a wide variety of goods, including wheat, dried peas, linseed, tobacco, hay, straw, etc.<sup>(9)</sup>

Other mites causing this type of dermatitis belong to the family Acaridae (Sarcoptiformes). Mites on cheese not infrequently cause trouble; they include *Tyrophagus casei*, *T. longior*, *Acarus siro* and *Glycyphagus domesticus*. Another source of trouble is copra, which may be infested with *Tyrophagus putrescentiae* (*T. castellanii*) or *Caloglyphus krameri*. Dried fruit, infested with *Carpoglyphus lactis*, has been implicated once or twice, and there is a record of *Suidasia nesbitti* on wheat.

Occasionally, outbreaks are sufficiently severe for a popular name to be coined to describe the disease. For example, 'copra itch' due to *T. putrescentiae*; 'grocer's itch' due to *G. domesticus*, which was formerly common on poor-quality sugar; 'vanillism' due to *T. casei* on vanilla pods.

### Control

Accidental dermatitis due to stored product mites clears up spontaneously when contact with the infested material ceases, usually within a few days. Soothing treatments, such as calamine lotion, may be desirable.

For persons obliged to handle infested materials, mite repellents (DMP: benzyl benzoate) may be beneficial. However, in view of the possibility of effects caused by dead mites (or their skins or faeces) repellents cannot be guaranteed to protect.

For control of the mites, see page 331.

## II·INVASION OF THE HUMAN BODY BY MITES<sup>(1, 30)</sup>

Various mites and their eggs, either living or dead, have been found to occur in various parts of the human body, such as the alimentary canal and the urinary and respiratory tracts. It should be remembered that, in investigating such cases, great care must be taken to exclude the possibility of accidental contamination of specimens or of laboratory glassware, for the mites concerned are ubiquitous. However, many records are probably authentic. The presence of the mites has been cited as the cause of various conditions including enteritis, nocturnal enuresis, haematuria and bronchitis. The evidence, however, is not straightforward, for in many cases the mites are quite harmless.

### Intestine

Since mites occur so commonly on many foods, they must frequently be swallowed by man and animals; and, in fact, they are quite often found in faeces. The most common species are *Tyrophagus casei*, *Acarus siro* and *Glycyphagus domesticus*. Nearly always the mites in faeces are found to be dead, but there are records of eggs hatching after passing through the alimentary canal. It seems possible that diarrhoea with occasional bloody discharges and even intestinal ulcers have been caused by continued feeding on food heavily infested with mites. There are several records of cases, both human and of animals, which have suffered these disturbances while producing stools containing numerous mites; and the symptoms have ceased on a

change of diet. Experimental studies have indicated a great variability in susceptibility of different animals to these effects.

### Lungs

Mites of the genus *Pneumonyssus* habitually live in the lungs of monkeys, apparently as a form of parasitism. Man does not appear to be susceptible to these mites, however. On the other hand, there are several records of various free-living mites being found in the sputum of patients suffering from asthma and eosinophilia, especially in the tropics (*Tyrophagus casei*, *Acarus siro*, *Histiogaster* sp., *Tarsonemus* sp., etc.). Whether the mites were responsible for the asthmatic condition is not certain. The numbers of mites found were small (one or two per patient) and the disease was cured by arsenical drugs, and it is difficult to see how these could have reached the mites.

### Other sites

Mites (mainly *Tarsonemus*, *Tyrophagus*, *Carpoglyphus*) have been found in urine, apparently from the urinary tract. There are also one or two records of mites found in pathological lesions; for example, in liquid from a scrotal cyst and in a carcinoma of the jaw.

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## II · *Pests of foodstuffs*

A variety of different insects preys upon domestic food stores. For convenience, they can be grouped together as 'larder pests', but they are rather a motley assembly with varying degrees of dependence on human food. Two rather different kinds of pest are included. The first group, which may be described as 'visitors', live in various harbourages in the structure of buildings (or even in the ground outside) and make journeys to visit the food stores. Cockroaches, ants, crickets and bristletails belong to this class. The second type of domestic food pests will be called the 'residents' because they live and breed in the stored food. These include certain beetles, moths and a number of mites.

### *A · Visiting Pests*

#### I · COCKROACHES (Blattidae)

##### (a) **Historical note**

The Romans mention an insect 'Blatta', but it is not certain whether it was a cockroach, a beetle or a moth. Mouffet (early seventeenth century) refers to this confusion, but does not really resolve it. He says, 'Now the Blatta is an insect flying in the night, like to a beetle, but wanting the sheath wings.' Unfortunately he then says, 'There are three sorts of Blattæ: the Soft Moth, the Mill Moth and the unsavory or Stinking Moth.' The 'Mill Moth' from his figure and description is clearly an adult *Blatta orientalis* while the 'Soft Moth' appears to be a male of the same species. The 'Stinking Moth', however, appears to be the beetle *Blaps*.

According to Laing,<sup>(28)</sup>

the common cockroach (*B. orientalis*) is supposed to have been introduced into England through commerce some time during the 16th century. . . . At first it was met with only in sea-port towns, and spread but slowly inland. Gilbert White, writing about 1790, speaks of 'an unusual insect' at Selborne. 'How long they have abounded in England, I cannot say; but have never observed them in my house until lately.'

On the other hand, the German cockroach 'is a comparatively recent arrival. It is generally stated that it was introduced during, or just after, the Crimean War, but this is open to doubt.'

The countries indicated in the specific names of cockroaches (*B. germanica*, *P. americana*, *P. australasiae*) are by no means reliable guides to their place of origin. *B. germanica*, in fact, is known as the Russian pest in Germany and the Prussian pest in Russia. An American entomologist comments:<sup>(30)</sup> 'European nationals name their cockroaches after their neighbours across the border, an honour which is always reciprocated.'

(b) **Distinctive characters**(i) *General*

Cockroaches belong to one of the primitive orders of insects, being allied to praying mantids, crickets, grasshoppers and stick insects. This is a very ancient assembly of insect types, formerly grouped together in a single order, the Orthoptera. Fossils not so very different from modern cockroaches occur in the upper Carboniferous 250 million years old.

Typically, cockroaches are rather large, robust insects, with whip-like antennae and two pairs of wings, the front pair being slightly stiffened and covering the hind pair when at rest. These front wings, however, show a distinct network of 'veins' which distinguishes them from the horny forewings of beetles.

(ii) *Identification of common species (Fig. 32)*

Cockroaches are most numerous in hot countries. There are, however, certain species which have become cosmopolitan and, in particular, some which have penetrated into cool climates by living exclusively in warm human habitations.

The species of cockroach most likely to be encountered in Britain may be distinguished as follows:

1. Yellowish brown, with two longitudinal marks on the thoracic shield; adults about  $\frac{1}{2}$  inch long, both sexes with fully developed wings  
German cockroach, *Blattella germanica*
2. Uniform, shiny, chocolate brown; adults about 1 inch long; male with wings covering  $\frac{2}{3}$  of abdomen; female wings reduced to short lobes  
Oriental cockroach, *Blatta orientalis*
3. Reddish-brown colour, thoracic shield with a yellow margin; adults about  $1\frac{1}{2}$  inches long; both sexes with fully developed wings  
American cockroach, *Periplaneta americana*
4. Similar, but with yellow wedge-shaped marks at the anterior corners of the front wings  
*P. australasiae*

(iii) *Relative prevalence*

The 'common cockroach' or 'black beetle' is *Blatta orientalis*; but, in the writer's opinion, it is now less prevalent than *Blattella germanica*. There seems to be no statistical evidence for Britain, but the following data from Denmark support this impression. During the five-year period 1959-63, the total inquiries to the Danish Pest Infestation Laboratory<sup>(6)</sup> concerning cockroaches comprised the following identified species: *B. germanica*, 161; *B. orientalis*, 18; *Periplaneta* spp., 4. It is generally found that *B. orientalis* is a pest of underground bakeries or of Victorian type kitchens; whereas *B. germanica* is characteristically a pest of modern centrally heated buildings, especially institutions.

*Periplaneta* spp. are not uncommon on ships but rarely occur ashore in Britain, except in warehouses at the docks and rarely in hothouses and certain other favoured places.

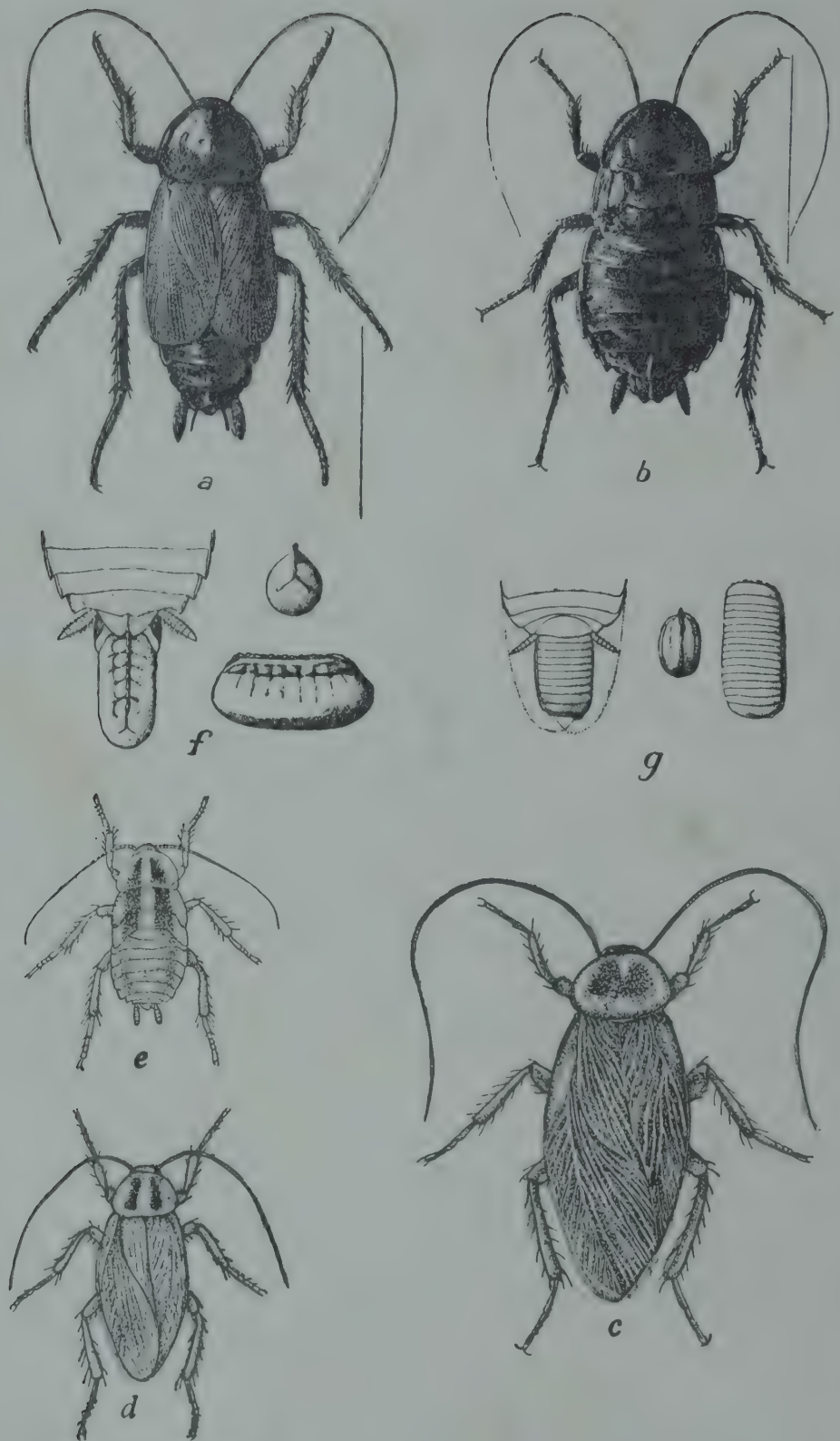


FIG. 32. Cockroaches. (a) *Blatta orientalis* (male); (b) the same (female); (c) *Periplaneta americana* (male); (d) *Blattella germanica* (female); (e) the same (nymph); (f) tip of abdomen of female to show the formation of egg capsule (*Blatta orientalis*); (g) the same (*Blattella germanica*). From Laing (1946) Brit. Mus. (Nat. Hist.) Econ. Series No. 12. (a) & (b)  $\times 1\frac{1}{2}$ ; (c)  $\times 1$ ; (d) & (e)  $\times 2$ .

(c) Life history<sup>(15, 36, 47, 51)</sup>

## (i) Oviposition

Female cockroaches lay their eggs in characteristic pod-like egg cases. These are formed in a chamber behind the egg pore which can be closed by a pair of flaps. Certain glands line the sides and back of this chamber with a viscous fluid, which is white at first but later turns brown and hardens. The eggs are laid into the pouch formed of this secretion and, as it becomes filled, the valve-like flaps relax and allow it to protrude. This occurs several times in the course of formation of the capsule, and the marks left by the retaining flaps can subsequently be distinguished as a series of ridges. In the later stages, the egg case can be seen projecting from behind the female as she runs about (Fig. 32). The cases are quite large compared with the size of the cockroach; those of *B. germanica* average 5.5 mm, of *B. orientalis* 10.5 mm and *P. americana* 9 mm. (Averages of six measurements from cockroaches reared at 25°C; 77°F.)

There are at least three types of behaviour of cockroaches in regard to oviposition.<sup>(49, 50)</sup> (1) Many species deposit and abandon the ootheca shortly after its formation. These include *B. orientalis* and *P. americana*. The former drops the ootheca without any special care, but the latter generally cements it to the ground and covers it with debris. The oothecae of these insects are well waterproofed and resistant to desiccation. On deposition they contain water in their spongy walls, which is absorbed by the eggs inside. (2) In other species the females carry the ootheca about with them until it is just ready to hatch. *B. germanica* is an example. After formation, the seam of the ootheca, which is vertical during formation, rotates 90° to one side or another. The anterior end of the ootheca, which is in contact with the female, is permeable to water and the eggs can absorb water from her, during development. (3) Another group of cockroaches extrude the ootheca during formation, but immediately afterwards draw it back into the female's brood chamber, where it remains until the young hatch, in an apparently viviparous manner. This group are not represented by domestic species found in Britain.

## (ii) Eggs

Inside the egg cases, the long narrow eggs lie in two rows, arranged alternately for compactness. The embryos are formed facing inwards, with their heads towards the aperture.

When they are fully developed, the young insects struggle upwards, burst open the closed seam and wriggle out. At the same time they undergo a moult and emerge as perfectly white, first stage nymphs. After a few hours the cuticle darkens and hardens; nevertheless, they are strong enough to run about immediately after hatching.

## (iii) Nymphs

The body form and habits of the nymphs do not differ greatly from those of the adults and will not be discussed separately. As usual with insects showing partial metamorphosis, there are gradual changes to the adult form, such as increases in the number of joints of antennae and cerci and the growth of the wing pads. If a

limb or antenna is damaged during the nymphal stage, it can be largely regrown in the course of subsequent moults.

Development is slow, even at high temperatures, and it is not easy to determine the exact number of moults, especially in view of the fact that the cast skin is usually eaten after moulting. In an investigation where the insects were reared separately and marked with paint to verify moulting,<sup>(62)</sup> the following numbers of nymphal moults were recorded – *Blattella germanica*, 6–7; *Blatta orientalis*, 7–10; *Periplaneta americana*, 10–13. It appears that injuries needing regeneration of an appendage may cause extra moults.

#### (iv) Adults

Apart from their mature sexual organs, the adults differ from nymphs in possessing fully formed wings. Even in species (*B. orientalis*) with degenerate wings, the adult wing stubs can be distinguished by their distinctly marked 'veins'.

The general appearance of a cockroach is fairly well known; and though *Blattella germanica* is sometimes called a 'steam fly' its true nature is apparent if it is critically observed. The head projects downward beneath the characteristic hood formed by the dorsal shield of the first segment of the thorax. The head bears the whip-like antennae which are frequently in motion gathering sense impressions. They are often cleaned, like other appendages, by drawing them through the mouthparts. In this way a cockroach may destroy itself by its cleanly habits; for after contamination with certain stomach-poison insecticides, the insect often swallows the poison cleaned off its limbs in this way.

Two large kidney-shaped eyes testify to fairly acute vision.

The mouthparts are primitive (and are commonly offered to students of zoology as a basic type). They are adapted to biting and triturating solid food and include stout mandibles and maxillae bearing hooked teeth and spines. Two pairs of palps are present.

Cockroaches can feed on practically anything edible and a large variety of substances may form their diet. Sometimes they occur plentifully in places where their source of food is problematical. When they live in warm, dry, centrally heated buildings, they need water; and they are sometimes trapped in sinks or wash-basins which they have visited in search of a drink.

The alimentary canal consists of a tube leading to a sack-like crop, where much of the digestion takes place, followed by a sort of gizzard with 'teeth' inside to grind up the food. The midgut begins with some blind pouches and continues as a simple, folded tube. At the beginning of the hindgut, a large number of Malpighian tubes are joined and they discharge their excreta into it among the food residues. The faeces vary in form according to the food, from dry pellets to dark-coloured liquid which forms smears.

The thorax bears the powerful legs and the wings, the latter being of minor importance or completely useless in the domestic species. The sturdy legs, especially the second and third pairs, are furnished with spines which give purchase on rough surfaces. If one picks up a large cockroach in a clenched hand, one is surprised at the energy with which it can thrust itself through a small crevice.

The feet of cockroaches comprise a central pad (the 'ariolium') and a pair of claws. In addition, the first four tarsal segments bear ventral pads called euplantulae. All these structures assist the insects in walking, especially on vertical or inverted surfaces. The claws, of course, are only helpful on roughened surfaces such as coarse paper. The ariolia and euplantulae, however, and especially the former, assist the cockroaches to walk on inclined polished surfaces. In *B. germanica* and *P. americana*, this ability enables them to climb up polished tiles or glass with ease. In *B. orientalis*, however, the ariolia are poorly developed and do not permit the females or some males to climb polished surfaces, though a few males are able to do so.<sup>(48)</sup>

*Blattella germanica* is quite active. The speeds achieved by this insect are as follows: males, 30 cm/sec on paper and 11 cm/sec on glass; females, 18 and 4 cm/sec respectively. This insect can also jump a few centimetres when alarmed (especially the males).

In temperate regions, none of the domestic cockroaches have been observed to fly, but in the southern states of the U.S.A., *P. americana* has been reported flying round street lamps at night like moths. This species, and *B. germanica*, may make gliding or fluttering flights in northern latitudes, but the action of the wings seems more to sustain gliding than actual flight. *B. orientalis* never uses its wings.

The cockroach abdomen is clearly segmented and bears at the end a pair of cerci, which are somewhat primitive appendages. On the dorsal side are scent glands, apparently responsible for the disgusting smell of the insect; and other glands, connected with sexual activity in some species.

Mating is initiated in *P. americana* by an odour omitted by virgin females which excites the males. In *B. germanica* no attractive odour, acting at a short distance, is involved. Direct contact with the female is necessary to induce sexual activity in the male and this usually happens by mutual stroking of the antennae. It appears that a chemical attractant is involved, since contact with male antennae or bristles will not do; yet the antennae of nymphs or of *B. orientalis* will excite males of *B. germanica*.

The copulation procedure is much the same in most species.<sup>(49)</sup> The excited male raises his wings vertically and usually vibrates them. He walks in front of the female and then moves backwards, bringing his abdomen under her body. During this stage, the female licks over his dorsal side, apparently being gratified by some secretions on it. Finally the male gropes for the female genitalia and, if successful, effects a union. Then the couples diverge until they face in opposite directions, while still connected by their sexual organs. They remain in this position for an hour or so. During this period, the spermatozoa are transferred to the female genital opening in a tiny bulb, the 'spermatophore'.

Ootheca formation begins a few days after copulation. Oothecae are also produced by unfertilized females, and in some cases there may be parthenogenetic development. The unfertilized eggs of *B. germanica* do not hatch; but some of them do in *B. orientalis* and, more frequently, in *P. americana*. These parthenotes can be reared to adults; they are always females. Generally speaking, however, parthenogenetic reproduction must be rare in most cockroach colonies.

### (d) Habits of nymphs and adults: dissemination

Cockroaches are gregarious, and collect together in various-sized groups of all ages. The big ones do not attack the smaller ones except when the latter are badly injured or are unable to escape from the old skin during a moult. Under such circumstances, cannibalism may occur. At one time it was believed that cockroaches will kill and eat bed bugs, but this appears to be a fable unfounded on fact.

Cockroaches are active at night, when they make their foraging journeys for food. People are sometimes dismayed by unsuspected large numbers of the pest scuttling for shelter when a light is suddenly put on at night. Experiments with *B. germanica* suggest that there are two periods of maximum activity, one shortly after dusk and another just before dawn.<sup>(61)</sup>

During the daytime, cockroaches hide in suitable harbourages (see p. 67). Warmth, darkness, moisture and a good food supply constitute the most favourable conditions. The following places are frequently infested: behind radiators or hot-water pipes, near ovens, gas-stoves or sinks, under pantry shelves, kitchen furniture and loose floor covering. *B. germanica* is particularly fond of warmth and, owing to its climbing powers, may be found at any level in a room; whereas *B. orientalis* is mostly restricted to floor level. *B. germanica* is a more thirsty insect and is usually only found in rooms where water is available. Normally, places near a food supply are most likely to be infested, but some cockroaches evidently make journeys of several dozen yards in a night. (This is proved by individuals of *B. orientalis* found stranded in such places as remote sinks and stone staircases from which they cannot escape.)

During the summer, it may sometimes happen that cockroaches migrate from moored ships to warehouses or from one building to another; but the domestic species are rarely encountered out of doors and by far the commonest means of dissemination is by means of wooden cases, carboys, and packages of all kinds.

### (e) Quantitative bionomics

#### (i) Effects of normal temperatures<sup>(15, 18)</sup>

Like other insects, the cockroach's rate of growth is more rapid at warm temperatures. But considerable variation is found in the lengths of stages in different individuals, even when they are kept under identical conditions. Under natural conditions this is accentuated by the seasonal changes of the prevailing temperature. Thus, of a batch of roaches hatching in the spring, some may complete their development the same year, but others will be checked by the winter and not reach maturity until the following summer.

Some approximate averages of the duration of embryonic and nymphal development are given in Table 12. Further data are available for 30°C,<sup>(62)</sup> the mean periods (days) for incubation and nymphal development being as follows: *B. germanica*, 17 and 41; *B. orientalis*, 44 and 155; *P. americana*, 39 and 179. The incubation periods agree roughly with those in Table 12 but the development times are shorter. It is known that cockroaches reared as isolated individuals are much slower in development than those reared in groups. These are from laboratory experiments at rather high temperatures. The slow development of cockroaches, especially the

TABLE 12 *Speed of development of eggs and nymphal stages of various cockroaches at different temperatures*

Temperature		<i>Blattella germanica</i>		<i>Blatta orientalis</i>		<i>Periplaneta americana</i>	
°C	°F	Eggs	Nymphs	Eggs	Nymphs	Eggs	Nymphs
30	86	15	74	42	300	32	194
25	77	28	103	57	530	57	519
21	70	24*	172*	81	—	88	—

Mean duration of stages in days. Data from GOULD and DEAY (1940) *Bull. Indiana Agric. Exp. Sta.* No. 451, except: \* from WILLE (1920) *Z. angew. Ent.* 7, Monag. No. 5.

larger species, clearly handicaps their proliferation in most houses in Britain. They can only breed moderately rapidly in buildings kept warm throughout the year. Owing to its shorter life cycle, *B. germanica* proliferates more rapidly than the other domestic species and is consequently a serious pest. (See also Fig. 8, p. 57.)

At the rather warm temperature of 25°C (77°F) the adults of the three common cockroaches were observed to live and reproduce as follows (approximate averages):

*B. orientalis* lived 140 days; produced 8 capsules ( 5 fertile)

*B. germanica* „ 260 „ „ 6 „ 4.4 „

*P. americana* „ 440 „ „ 53 „ 33 „

The egg cases of *B. orientalis* and *P. americana* both average about 16 eggs, while those of *B. germanica* contain about 30; in all cases there is considerable variation.

#### (ii) Abnormal temperatures

The lethal high temperatures for the relatively short exposure of one hour is about the same for all three of the common cockroaches, viz.: 42–43 °C (107–109°F) in moist air and 45–46°C (113–115°F) in dry air. The higher temperature in dry air can be withstood because cooling due to evaporation from the insect's body is not prevented. In a long exposure (24 hours) the benefit of cooling by evaporation is more than offset by the deleterious effect of desiccation. Corresponding figures for lethal temperatures are: 38–39°C (100–102°F) in moist air and 37–39°C (98–102°F) in dry air.

There appears to be little data concerning the resistance of cockroaches to low temperature. It is stated that half an hour at –5°C (23°F) is fatal. The effects of low temperature depend to a considerable extent on the previous environment.

#### (iii) Food

In spite of the omnivorous nature of cockroaches, their growth, development and egg production are retarded if they are fed on artificial or incomplete diets. However, they can maintain their body weight for considerable periods on a diet completely lacking in proteins. After a period of retardation they will immediately begin to grow and develop when they return to a full diet.

Cockroaches cannot be included among insects which are able to subsist for long

periods on food stored in their bodies. Adults of *B. orientalis* starve to death in 3 to 6 weeks at 25°C.<sup>(65)</sup> All nymphs of *B. germanica* lived for about 3 weeks without food and the males and females died after 2 and 5 to 6 weeks respectively.<sup>(61)</sup>

#### (f) Importance

Under certain circumstances, it is possible for cockroaches to act as mechanical vectors of disease germs.<sup>(24, 50)</sup> They have been observed to feed on cholera dejecta and on infected sputum of corpses dead from tuberculosis. Experiments have shown that several types of bacteria can pass through the intestines of roaches without being destroyed. Under normal circumstances roaches do not have ready access to virulent pathogens, but their presence in such places as hospitals may be not without danger. Evidence that cockroaches were responsible for transmission of *Salmonella typhi-murum* was obtained in a children's ward of a hospital in Brussels.<sup>(17)</sup> Where cockroaches are present in a hospital, it is essential to immerse septic dressings, etc., *completely* in disinfectant, rather than to put them aside for incineration. Control measures also are obviously necessary.

On the whole, the cockroach is less likely to carry infection than the common housefly, because, though its habits are equally unpleasant, its mobility is less. The usual objections to roaches are their spoiling of food by nibbling it and dropping excrement on it, the unpleasant smell associated with them and the general feelings of disgust they arouse.

#### (g) Control measures

##### (i) Preliminary inspection

The first essential in dealing with a cockroach infestation is to obtain a good idea of the extent of the infestation and the principal harbourages used by the insects. One method is to visit the premises in the hours of darkness and switch on the lights. Many wandering cockroaches will be revealed and most will run to their hiding places, which will thus be disclosed. If the inspection visit is made in the daytime a torch should be used to examine likely harbourages, especially places near sources of warmth (hot-water pipes) or moisture (sinks and drains). An aerosol dispenser containing pyrethrins will also be found useful, to flush out cockroaches from inaccessible places.

##### (ii) General measures<sup>(64)</sup>

So far as possible, harbourages should be denied to the cockroaches by sealing cracks and crevices, especially those round hot-water pipes entering rooms; these should be filled with putty or steel wool. Ducts and chases should be made to open for inspection and treatment if they cannot be completely sealed.

All areas should be thoroughly cleaned so that no food particles, debris or rubbish are left to provide nourishment and shelter for the insects.

##### (iii) Insecticide treatments

Contact insecticides may be applied as direct sprays or as dusts, for ease and convenience; but residual treatments will be more radical in effect. DDT is not especially effective against cockroaches, but *gamma* BHC or chlordane are very effective,

unless resistance is present. (This type of resistance has developed in *B. germanica* in many places.) Diazinon or malathion are suitable alternative contact poisons; or chlordecone can be used as a stomach poison.

*Direct sprays* (applied by hand atomizer) or *aerosols* (used as direct sprays) can only be relied upon to kill the insects contaminated by the spray jet. Therefore several treatments will be necessary. Nevertheless, by repeated and determined efforts this will achieve good control. Synergized pyrethrins (see p. 127) would be a suitable insecticide.

*Lacquers* containing high residue of organo-chlorine insecticides have given the most efficient and prolonged control of cockroaches (see p. 131). However, they are somewhat expensive and require expert application.

*Residual spray* should be applied to all areas where cockroaches hide or run about. This may involve treatment of about 20% of the area of the room. For normally susceptible cockroaches, sprays containing 2.5% chlordane, or 1% *gamma* BHC give excellent results. In case of resistance 3% malathion, 2% fenchlorphos or 1% diazinon should be used.<sup>(16)</sup>

Residual sprays should be applied with care in kitchens or larders, to avoid any possible contamination of food.

*Dusts* may be blown into crevices and infested ducts where spray deposits will not reach. In general, however, the dust deposits necessary along cockroach runways, etc., are somewhat unsightly and are liable to be swept up, thus preventing a residual action. Suitable dusts should contain either 1% *gamma* BHC, or 5% malathion, or 3% diazinon. As before, treatments in food-manufacturing establishments should be done with care.

*Baits* consisting of pellets containing 0.125% chlordecone (see p. 95) have been widely used to supplement other control measures against German cockroaches in the U.S.A. The pellets are placed on small trays or scattered in concealed locations.

#### (iv) *Repellents*<sup>(14, 20)</sup>

Limited applications of repellents may be found useful to keep cockroaches out of particular places (food packages, valuable apparatus, etc.), especially if insecticide resistance has developed. Some years ago cockroach-repellent qualities were claimed for a magnesium oxychloride cement containing finely divided copper. More recently various chemical treatments have been tried, one of the best being 'R874' (2-hydroxyethyl *n*-octyl sulphide). The persistency of this compound can be improved by addition of a synergist and its power (and versatility to cockroach species) extended by use in combination with synergized pyrethrins.

#### (v) *General remarks*

Many insecticides will kill cockroaches and, in a heavy infestation, will secure a gratifying number of corpses. Nevertheless, eradication is very difficult to achieve, because most of the insects and all the egg cases are liable to be hidden away protected from everything except a penetrating fumigant. Thus young insects may hatch undisturbed and appear a number of weeks after an apparently successful treatment.

The best way to exterminate the pest is to persist with treatment systematically until all the cockroaches are certainly destroyed. Therefore, an intelligent and conscientious operator with adequate time is more important than the exact choice of insecticide. The advisability of employing a professional pest control operator should be considered where a large institution is concerned (see p. 76).

## II · ANTS (Formicidae)

### (a) Historical notes

Ants have attracted the attention of man from ancient times; the biblical proverb extolling their industry is well known. The unpleasant nature of the stings of certain ants is referred to by Shakespeare in Henry IV (Act I, Sc. iii) when Hotspur declares:

*Why, look you, I am whipped and scourged with rods  
Nettled and stung with pismires . . .*

Pismire is an old English word for the ant derived from the Nordic roots 'piese' a heap and 'myre' an ant (which reference to the ant-hills). The modern word ant is a corruption of the older term 'emmet'.

### (b) Distinctive characters

#### (i) General

Ants are among the most highly evolved of insects. They belong to a fairly advanced order, the Hymenoptera, characterized by biting mouthparts and two pairs of membraneous wings; the second pair being smaller than the first and hitched on to them by a row of tiny hooks. The higher members of the order (ants, bees, wasps) have a very narrow waist between thorax and abdomen. In the ants, this waist bears one or two small expansions or knobs; another characteristic of all ants is their antennae which are 'elbowed' or held like a bent arm. Like all higher insects they have complete metamorphosis.

More interesting than the specialized structure and development of ants is their complex social system and development of castes. This may be presumed to have originated as follows: From the gregarious habit (common in many insects) there developed nursing instincts to care for the helpless larvae. It probably came to pass that some of the females assumed more of the duties of hunting and foraging and at the same time became less fertile. Finally a caste of sterile females or 'workers' arose, differing in size and form from their fertile sisters. The workers are usually much smaller than the sexual forms and never develop wings. Thus there are three primary forms in the ant colony: males, females (or 'queens') and workers (which may show minor modifications). The factors which determine whether an ant will become a fertile female or a sterile worker are not fully understood. Some authorities believe that this is predetermined genetically in the egg. On the other hand, there is much evidence that nutrition supplied to the larvae can influence the production of sexual forms (as it does in the honey bee, whose queens are produced by feeding certain larvae with a special diet). It also appears that the rate of egg production in ant colonies can affect the development of sexual forms. Young colonies, with females

laying sparsely, produce only workers; whereas flourishing colonies with plentiful food and egg production give rise to sexual forms.

Although worker ants are virtually sterile, they will sometimes lay eggs and occasionally these unfertilized eggs will develop (into males or workers). Generally, however, such eggs are eaten by the ants.

The complex behaviour of many ants has attracted the attention of several eminent naturalists and a voluminous literature describes their astonishing interdependence within the colony, their battles with other ants and slave-making habits, as well as the divers curious insects which live in ant nests.

(ii) *Identification of important species*<sup>(7, 41, 63)</sup>

There are several thousand species of ants but less than forty occur in Britain. Very few of our indigenous species, which form nests out of doors, enter houses; indeed the only one which does so commonly is *Lasius niger*. There are a few recent records of invasions of a related ant, *L. brunneus*, and some old references to *Ponera punctatissima* indoors. About ten different ants from tropical countries have been found living entirely in heated buildings in Britain; but the great majority of these were in the highly specialized environment of hothouses at botanical gardens. A few of these exotic species have occasionally invaded warm buildings, such as bakehouses (e.g. *Paratrachina longicornis*, *Pheidole megacephala*, *Tapinoma melanocephalum* and, slightly more frequently, *Iridomyrmex humilis*). While, however, heated buildings provide tropical warmth, they are not humid enough for most ants and only one species has managed to thrive in many centrally heated buildings. This is *Monomorium pharaonis*, which has been established in Britain for at least 100 years.

The great majority of complaints of ants in buildings are due to *Lasius niger*, the

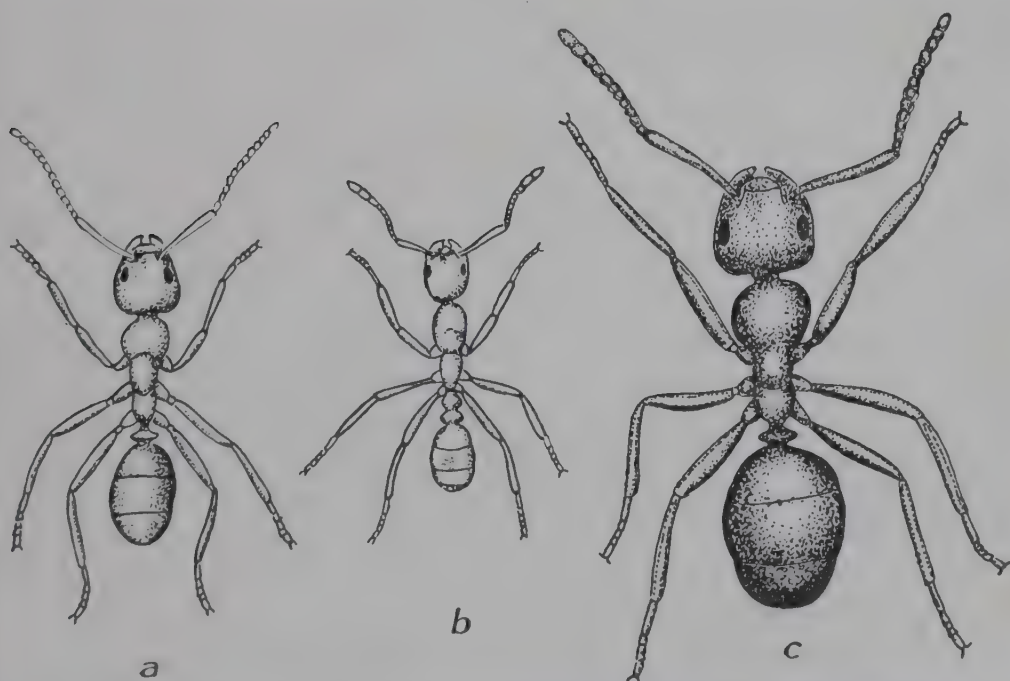


FIG. 33. Workers of ants liable to infest houses in Britain. (a) *Iridomyrmex humilis*; (b) *Monomorium pharaonis*; (c) *Lasius niger*. (Partly after Gosswald, *Z. hyg. Zool.* 20, 202.)  $\times 13$ .

black garden ant, and *Monomorium pharaonis*, 'Pharaoh's ant'. The former often invades ordinary dwelling houses from nests in the garden, during the summer; the latter forms nests indoors, in centrally heated buildings (often institutions) and may be troublesome at any time of the year. The two species may be distinguished as follows:

(i) Larger ants (3.5–5 mm) dark brown or black; one knob in the waist  
*Lasius niger* (Fig. 33c)

(ii) Small ants (1.5–2.4 mm), sandy coloured; two knobs in the waist  
*Monomorium pharaonis* (Fig. 33b)

*Lasius brunneus* may be distinguished from *L. niger* by its dirty yellow-brown colour and the long first joint of the antennae being bare, whereas this joint in *L. niger* bears outstanding hairs.

*Iridomyrmex humilis* workers are 2.2–2.8 mm, brown and with a single knob in the waist (see Fig. 33a).

### (c) Life histories and quantitative bionomics

The life history is complicated by the social system which subordinates the individual to the community. It is, therefore, convenient to consider the development of a new colony or infestation.

#### 1. The common black ant (*Lasius niger*)

After mating, the females break off their wings and dig a cell in the earth. Here they lay their eggs and rest until they are hatched. The young are white, helpless grubs without legs. The mother feeds them with secretions of her salivary glands, until they are mature. Finally they pupate and then emerge as adult workers. During the whole of this time, the female takes no food but subsists on stores in her own body. Her fat-body and the muscles of her wings are broken down for food. When the first workers become adult, they take over the duty of feeding and tending the queen and her subsequent brood. The workers forage in all directions for food, bring it back in their crops and feed it in a semi-liquid condition to the queen and grubs. The ant 'nest' formed in this way may last for several years.

*Lasius* feeds on a variety of substances; it kills and devours small flies and similar insects, visits flowers for nectar and collects seeds. In addition, it has the remarkable habit (like certain other ants) of tending aphids and imbibing the sugary excretion which they produce so copiously.<sup>(21)</sup> The workers travel considerable distances in their search for food and find their way about mainly by a sense of smell. Thus, they can follow long trails of scent drops left by themselves, or their sister ants. When they have found a good source of food, they are able to communicate the fact to their colleagues in some way (possibly by tapping them with their antennae). Consequently, when these ants nest close to a house, it often happens that a worker finds a rich harvest in the human larder; and soon there is a line of ants going each way along a trail from the nest to the food.

In addition to their foraging duties, the workers enlarge the nest and make numerous galleries and cells of earth. Also they tend and clean the grubs and the queen. If danger threatens they remove them to safety. Thus, when one digs into an ant

nest one sees the workers energetically carrying away what are commonly called 'ant eggs' (goldfish food!), though the so-called eggs are nearly as large as themselves; these are the pupae.

During the late summer, sexual forms are produced in large numbers. The males are bigger than the workers and the females larger still; both sexes possess the transparent wings characteristic of the order. These sexual individuals all emerge from the nest on the same day and mate as they fly away in all directions. This phenomenon of 'swarming' often happens in many nests over a wide area on a particular day, usually in the afternoon. This 'swarming' phase occasionally gives rise to trouble inside houses (e.g. when a nest has been built in the earth underneath them). Complaints of 'flying' ants should not be serious for the nuisance is of short duration.

After mating, the males usually perish and only a very small proportion of the females survive to form a new colony. Sometimes two or three fertilized females are found in the same or adjacent earth cell but normally one dominates the others and eventually kills them. Colonies are very rarely found with more than one queen. She is the vital centre of the nest which gradually dies out if she is removed.

### *Quantitative bionomics*

Quantitative laboratory studies of the speed of development, etc., of *L. niger* do not seem to have been made. Instead, there are scattered observations of naturalists as follows: fertilized females established in an artificial nest in March laid eggs in April.<sup>(5)</sup> By the beginning of July pupae were present and workers began to emerge at the end of July. The following records were made of the related *L. niger americanus* in Illinois. The fertilized females enter the soil in the autumn though they may not lay their first eggs until the following May. The first workers emerge in July. The egg stage lasts 22 to 28 days; the larval stage 16 to 23 days. During the summer the entire life cycle takes about two months.

### 2. Pharaoh's ant (*Monomorium pharaonis*)<sup>(44, 55)</sup>

The biology of this ant differs in several respects from that of *Lasius* mainly because of its tropical origin. The nests are formed in hollow spaces in the walls and beneath the floors of buildings. These ants favour warm humid conditions and often make nests behind stoves or kitchen ranges and particularly in steam-heated buildings in the vicinity of hot-water pipes. These nests are usually very inaccessible.

On account of its environment *Monomorium* lives under very uniform conditions, and it is relatively unaffected by the season. Thus sexual forms are liable to occur at almost any time of the year; they have been observed (in Dundee) in every month except January and February. Batches of sexual forms occur at rather irregular intervals. In laboratory cultures kept at 27°C (80°F) the majority of colonies swarmed at intervals of 11 to 37 days; but intervals of 43 up to 200 days were also observed. The period over which sexual forms were produced was usually 2 to 3 weeks (i.e. the time from detection of the first sexually destined larva to emergence of the last sexual adult). Of the adult sexual forms emerging, females always predominated. The numbers of females per 100 males ranged from 110 to 525.

Although sexual forms are winged, flying swarms are never observed in Britain. Mating takes place in the interstices of infested buildings. The formation of a new colony is not normally accomplished by a single female after a nuptial flight, as with many other ants. Indeed, laboratory colonies do not thrive unless there are several 'queens' present. The usual mode of formation of new colonies would appear to be undertaken by a large part of the colony, the workers carrying with them some or all of the eggs and young stages. This general migration may occur at any time when the original colony has become large and with numerous sexual forms. It is very easy to encourage this type of formation of new colonies by providing a suitable site for colonization (e.g. a tin furnished with a water-soaked cotton wool pad). New colonies formed in this way in infested buildings have been found to contain from 400 to 4800 ants (of all stages) including 5 to 110 females, 0 to 5 males and 150 to 1000 workers. Sub-cultures may be obtained in an analogous way in the laboratory. When two colonies co-exist in a single large container, they intermingle amicably. It is obvious that this ready formation of new colonies must facilitate the spread of the ants through suitable buildings and form numerous pockets of infestation. Clearly they are a difficult pest to eradicate.

The tiny workers of this species penetrate all over large buildings in their search for food. The 'queens' too can often be observed among the processions of workers; they are easily recognized by their larger size. This ant shows a love of warmth which may be noted in the way in which their trails will follow the course of hot-water pipes.<sup>(2)</sup> Occasionally trails diverge from the quest for food to sinks or drains in search of water. All sorts of edible material will serve as food, including sugar, jam and honey as well as proteins (meat or cheese) and fats (butter, dripping). They display astonishing powers of finding such things in cupboards and drawers even in packets and jars. After one ant has discovered the food, a crowd of them soon collects and surrounds it, gradually removing it in small quantities.

#### *Quantitative bionomics*<sup>(44)</sup>

The following data relate to laboratory colonies maintained at 27°C (80°F).

*The duration of various stages (days).* E, 7½; L, 17; pre-P, 3; P, 9; total 37. This is for workers; the sexual forms require about 3 or 4 days more for development.

*Longevity of adults.* Females live longest, the maximum observed being 39 weeks; workers come next with a maximum of 9 to 10 weeks. The life of the males depends largely on opportunities for pairing and can range from 3 to 8 weeks.

*Egg production.* An average egg-yield of 350 per female is quite possible in a thriving colony, corresponding to an average of 1.5 per day.

*Mortality during development* was high in laboratory colonies (about 75%). Most of the deaths occurred in early life, sometimes due to cannibalism.

*Sex ratio.* Females are more prevalent than males, approximately in the ratio 2 or 3 : 1.

### 3. The Argentine ant (*Iridomyrmex humilis*)

This ant, also a tropical invader, is confined in Britain to warm buildings. There may be several queens to a nest and these wander about to some extent. Though

this ant is hostile to other species, the workers of several colonies mix without fighting (unlike many other types of ant). Large aggregate nests may therefore exist, completely intermingling.

### *Quantitative bionomics*

The following data relate to an artificial colony.<sup>(40)</sup>

*The duration of the various stages (days).* E, 27 at 22°C (71°F) and 20 at 27°C (80°F); L, 60 at 11°C (52°F), 50 at 17°C (62°F) and 15 at 25°C (77°F); P, 25 at 14°C (57°F), 14 at 25°C (77°F), 11 at 27°C (80°F). These figures are for workers; sexual forms develop more slowly.

### (d) Importance

Pharaoh's ant is a common pest in hospitals, where, in certain circumstances, it could transmit disease germs. Two of its habits suggest this possibility. In the first place, it often visits moist or liquid substances for water and has been seen at different times in drains, urinals, on faeces, wet dressings and sputum. Secondly, the foraging workers have astonishing intrusive powers and get through tiny crevices in closed containers. They have been found in 'sterile' dressings, surgical gloves and syringe dishes. By reason of its wide range, ants may travel to many parts of heated buildings and appear in such undesirable places as operating theatres, dressing stores and laundry baskets.

Another unpleasant habit of Pharaoh's ant in hospitals is to bite the eyelids and other parts of young infants, causing considerable irritation.

A general objection to all kinds of house-invading ants is the unpleasant site of numerous workers clustering on food. Their depredations are slight, but may be sufficient to damage the appearance of foods, for example, by biting holes out of iced cakes.

### (e) Control of ants in houses<sup>(38, 41, 57)</sup>

#### (i) *Destruction of the nest*

This is the best and only certain method of eradication. Unfortunately it is very difficult to achieve with *M. pharaonis* or *I. humilis* because the nests are so inaccessible, the trouble of dismantling walls and flooring must be balanced against the seriousness of the nuisance caused by the ants.

With infestations of the common black ant it is often possible to trace the trails of worker ants back to their nest in the soil. The nest should be dug open and destroyed, either by pouring in a liberal quantity of boiling water or about a pint of carbon tetrachloride. If carbon tetrachloride is used, the nest should afterwards be covered with damp soil to retain the fumes.

An alternative method of destroying nests of garden ants, which may prove simpler, is to sprinkle the area liberally with 0.2% emulsion of chlordane from a watering can. At this strength, the insecticide should not harm the vegetation. On paths or outside walls, where no contamination of plants will occur, a stronger solution (2%) may be used, somewhat less liberally.

*(ii) Trap baits*

Large numbers of worker ants may be destroyed if suitable trap baits are scattered about and the ants clustering round them periodically destroyed. Suitable traps are pieces of sponge moistened with syrup or (especially with *Monomorium*) scraps of meat or raw liver. The ants can be easily destroyed by plunging the baits into boiling water. Nevertheless, this procedure is not likely to exterminate a colony. In one institution, this method was continued for 700 days against *M. pharaonis*. During this time, careful estimates put the number of workers killed at  $5\frac{1}{2}$  millions and 6000 queens were also destroyed, without eradicating the pest.

*(iii) Residual treatments*

The best method of eradicating Pharaoh's ant from infested buildings is by surrounding the area of the nests with an insecticidal residue. The most efficient and long-lasting treatment is to apply a lacquer containing an effective insecticide (see p. 131). Alternatively, the perimeter can be sprayed with 2% chlordane (emulsion or suspension). To delineate the infested area, trap baits (as described in the previous section) are scattered about and the ones visited by the ants marked on a suitable plan of the building. A suitable sprayer is used to apply the insecticide to the wall-floor junction up to a height of 2-3 feet and also round radiators, built-in cupboards and door-frames. Particular attention should be given to ant trails and also the points where such trails disappear (and may therefore approach a nest). Rooms immediately above or below the treated area may need spraying, since trails often run from one floor to another.

Although one spraying usually gives a substantial degree of control, it may be necessary to repeat the treatment once or twice (at monthly intervals) to secure complete eradication.

*(iv) Poison baits*

The principle of the poison bait is to use a poison not too rapid in action, so that the workers will be able to return to the nest and feed it to the queen and brood. By this means the insecticide is taken to the heart of the infestation. Good results have been obtained with the method but it needs to be done thoroughly and persisted with for two or three months, or even longer, until successful.

The disadvantages of poison baits are that they must be applied in such a way that children or domestic animals will not eat them and also that they must be renewed at least weekly, which is troublesome.

The following is a suitable formula: water, 51%; sugar, 42%; honey, 6%; sodium fluoride, 1%. The mixture should be warmed and thoroughly stirred together. It is then kneaded into a mush with 1-2 parts of a solid carrier (cake, minced meat or chopped liver).

Although baiting is slower and more troublesome than spray treatments, the method may need to be revived should the ants become insecticide-resistant.

*(v) Repellents*

One of the objectionable habits of Pharaoh's ant, when it occurs in hospitals, is its

tendency to get into patients' beds. Therefore it is sometimes necessary to prevent access of the ants to beds, even if the general infestation cannot be easily eradicated.

The ants can be prevented from climbing up the legs of beds, cots and tables by smearing the legs once or twice weekly with either a strong insecticide or else a repellent.

### III · THE FIREBRAT (*Thermobia domestica*)

#### (a) Distinctive characters

The firebrat is related to the more common silverfish, *Lepisma saccharina*; both belong to the primitive order Thysanura. Insects of this group are wingless and moult in the adult stage; they have long, simple antennae and three tail-like processes at the back of the body (Fig. 46, p. 403). Abdominal appendages ('styles') are present underneath the seventh to ninth abdominal segments of older insects. About two species occur in Britain; two of them can occur indoors as domestic pests, the silverfish and the firebrat. The former, which is mainly a pest in rather damp rooms, is dealt with in Chapter 16 as a nuisance. The firebrat, however, only flourishes in warm conditions and is confined to such places as kitchens and bakeries. It is greyish in colour, speckled with darker markings.

#### (b) Life history<sup>(29, 60)</sup>

##### (i) Oviposition

The female lays eggs in batches, each one in a different stage of the adult life. A separate fertilization is necessary for each batch. The insects tend to lay more eggs if they are undisturbed.

##### (ii) Egg

The egg is soft white and opaque when laid; weighs about 0.3 mgm and measures about  $1 \times 0.8$  mm.

##### (iii) Nymph

As with *Lepisma*, the young are hatched without scales and acquire them at the fourth stage. Three pairs of styles appear in the females in the 5th, 8th and 10th instars; the last pair seldom develop in males. Egg-laying has been observed to begin in the 14th to 17th instars in different individuals.

##### (iv) Adult

Moulting continues in the adult life and as many as 60 stages have been recorded. The speckled markings of the adult are similar to those of the younger insects, but somewhat more distinct.

The food of the firebrat, like that of the silverfish, consists largely of carbohydrates made up with small amounts of protein. In kitchens and bakeries the firebrat finds a ready source of nourishment in crumbs and dust of flour and other food residues.

The mating procedure has been observed; it is somewhat unusual. The male performs a sort of 'love dance', turning about in short circles and repeatedly contacting the antennae, mouthparts and legs of the female. Finally he deposits the sperm bag (spermatophore) about half an inch in front of her and loses interest in the proceedings. The female now moves forward, straddles the spermatophore and receives it into her genital opening.

### (c) Quantitative bionomics: ecology<sup>(56)</sup>

#### (i) Temperature

The eggs will not hatch at or below 22°C (71°F) nor will development be completed at 25°C (77°F). Lethal high temperatures at 49°C (120°F) for 1 hour; 48°C (118°F) for 10 hours; several days at 47°C (116°F).

Over the range permitting full development, the incubation and maturation times (days) are as follows:

	27°C 80°F	29°C 84°F	32°C 90°F	37°C 98°F	42°C 107°F
Incubation	44	32	21	12	9.5
Maturation	330	247	105	92	47

Under optimum conditions (37°C and 80% R.H.) the duration of an instar increases from 2 to 11 days, in the first 8 instars, and thereafter remains at about this length for the rest of the insects' life.

The sexually mature females are able to mate from the 1st to the 5th day of the instar, but usually do so in the first 3 days. Males continuously exposed to females can mate for most of the time, but are most potent in the first third of the moulting cycle.<sup>(60)</sup>

The adults can live for 2 to 2½ years at 32°C or 1 to 1½ years at 37°C.

#### (ii) Humidity

At a favourable temperature (37°C; 98°F) some eggs will hatch at humidities as low as 11% R.H. and normal emergence occurs at 33% R.H. and above. Development is completed at 50% R.H. and above with or without a free water supply; though they do better with water available at the lower humidities.

### (d) Importance

The very warm temperature preference of the firebrat restricts its prevalence to the vicinity of the oven in bakehouses and kitchens. To a certain extent it may be considered a food pest, since it presumably feeds on flour etc. spilt in such places. Its digestive enzymes are capable of coping with fats as well as starch and protein, so that it may be regarded as omnivorous.<sup>(59)</sup>

In some bakeries it has been found to nibble small holes in loaves. It also has the curious habit (like the silverfish) of biting holes in inedible fabrics, especially viscose rayon. Apart from this, the sight of these insects crawling over the walls and shelves is disagreeable; and there is always a chance that one of them may be found in the bread or rolls sold from an infested bakery.

### (e) Control

The firebrat, unfortunately, usually thrives in rooms which must necessarily be kept in a condition favourable to development of the insect. Thus a bakery cannot be allowed to become cool merely to discourage the pest.

Direct attack by insecticides is difficult, in view of the pests' proximity to food. Spraying the walls with 6% DDT in kerosene has been reported as successful,<sup>(30)</sup> but the author has seen one infestation in which this treatment failed. The use of electrically heat-generated aerosol of *gamma* BHC has been recommended in the U.S.A. Probably the safest insecticide for use in bakeries would be a synergized pyrethrum spray. It is likely that repeated treatments would be necessary and they should be combined with thorough cleansing measures to discourage the pest.

## IV · THE HOUSE CRICKET (*Acheta domesticus*)

The common and scientific names of *Acheta domesticus* are both suggestive of the infestation of human dwellings and there is little doubt that, at one time, crickets were common inhabitants of warm kitchens. Since they are omnivorous, they probably lived on any scraps of food debris; perhaps they also raided the larder at night.

In recent years, however, crickets are rarely, if ever, permanent house dwellers. Living mainly on refuse tips, they sometimes tend to invade neighbouring houses during the winter. Their chief impact is as nuisances rather than food pests and accordingly they are dealt with in Chapter 16 (p. 420).

## *B · 'Resident' Pests*

Human food stores, whether the huge accumulations in silos and warehouses or small domestic reserves, offer relatively enormous supplies to insects and mites which can live and breed in them. The only limitation is that most stored products have a rather low moisture content. For example, that of Australian wheat is generally about 11%, cocoa beans and groundnuts are usually 6 or 7%, while barley malt is only about 3%. Consequently, the pests best able to thrive in stored food are those adapted to rather dry environments; and indeed some of them conserve the water produced by their own metabolism.

The great majority of insect pests of stored products belong to two orders: the Coleoptera (or beetles) and the Lepidoptera (or moths). These insects are most troublesome under warm conditions. Less restricted by low temperature but more dependent on high humidity are mites which infest stored foods.

Nearly all of the various insect pests, which will be described in the following pages, have been recorded from a wide variety of stored foods, spices and drugs, and a large proportion of them can be reared satisfactorily on many substances. Nevertheless, many pests are typically associated with a particular type of product. This probably reflects the ancestral habits of the insect, which may have been to attack whole seeds, damaged seeds, dried fruits or nuts or animal remains. Thus:

GRAIN PESTS (originally attacking seeds) include: *Sitophilus* spp., *Cryptolestes* spp., *Oryzaephilus* spp., *Trogoderma granarium*, *Rhizopertha dominica*. Also *Ephestia elutella*, *Sitotroga cerealella*.

PULSE PESTS (attacking larger seeds) are represented by Bruchidae.

FLOUR AND GROUND CEREAL PESTS (originally attacking seeds damaged by other insects, etc.) include: *Tribolium* spp., *Gnathocerus* spp., *Tenebroides mauritanicus*. Also *Anagasta kühniella*.

DRIED FRUIT AND NUT PESTS include: *Oryzaephilus* spp., *Carpophilus hemipterus*. Also *Plodia interpunctella*, *Cadra cautella*, *Paralipsa gularis*, *Corcyra cephalonica*.

ANIMAL HIDE AND BACON PESTS (originally attacking dried cadavers) include: *Dermestes* spp., *Necrobia rufipes*.

A MISCELLANEOUS GROUP (possibly derived from scavengers) includes: *Stegobium paniceum* (miscellaneous cereal products and drugs), *Lasioderma serricorne* (often on tobacco), *Ptinus tectus*.

It must be stressed, once again, that these associations are not at all rigid. Thus, *E. elutella* is a common pest of cocoa and chocolate, *P. interpunctella* attacks maize seed, *Lasioderma serricorne* is a serious pest of cocoa, *Necrobia rufipes* thrives on copra.

## I · BEETLES (Coleoptera)

### (a) Historical note

It is probable that since man began to store food or seed corn from one harvest to the next, insect pests have attacked such stores. Supplies of grain placed in the tombs of the ancient Egyptians have been found destroyed by familiar pests. In the tomb of Tutankamen, for example, remains of the following beetles were found: *Lasioderma serricorne*, *Stegobium paniceum*, *Gibbium psylloides*.<sup>(1)</sup>

### (b) Distinctive characters

The beetles are among the most easily recognizable insects. Their main characteristic is their stiffened forewings (devoid of any trace of 'veins') which cover the hind wings when at rest, lying above the abdomen and meeting in a straight line. Most beetles are well-armoured insects and, though many can fly, in general they are a pedestrian group. The mouthparts are always adapted for biting. Beetles undergo complete metamorphosis during development and various types of larvae are found, ranging from the active primitive type to a legless grub (see Fig. 3, p. 31). The active larvae are typical of the more primitive families.

#### *Identification of beetle pests of food*

A key is provided in the Appendix (p. 454) to permit identification (with the aid of illustrations) of about a score of the beetles most commonly found in stored food-stuffs. Technical terms have been reduced to a minimum to facilitate the use of this key by anyone with a modicum of entomological knowledge.

(c) **Occurrence and life histories of various pests**<sup>(4, 26, 47)</sup>

This section deals with some aspects of the more frequently encountered stored product beetles; the space allotted to each is roughly in accordance with their importance. They occur in six of the superfamilies of polyphagous beetles given in the revised edition of Imms' *A General Textbook of Entomology* (1957) and listed in the same way, grouped under families and genera. Short keys are given to distinguish the more important species and a few notes on general appearance are usually given to confirm identification. The common names given are those recommended by the Ministry of Agriculture, Fisheries and Food, Technical Bulletin No. 6. Prevalence and distribution are mentioned, and information given of the type of products attacked. The life history is outlined and the speed of development indicated by the following code: figures following E, L and P give the average duration of egg, larval and pupal stages (in days, except where stated) at the temperature indicated.

## DERMESTOIDEA

*Dermestidae* (hide and carpet beetles)

The name *dermestes* is derived from the Greek and means 'skin-eater'; the common English names connote the same habit. These beetles are pests of hide, skins and woollen materials. They are dealt with more fully in the chapter on wool pests, but some mention must be made here of species that feed on food products. Thus:

*Dermestes lardarius* (bacon beetle) sometimes occurs, as its name implies, in domestic larders feeding on dried eggs and other proteins. This pest and also *D. maculatus* are sometimes prevalent in dog biscuit factories and the larvae are sometimes found inside the biscuit. (They are dealt with more fully on page 362 *et seq.*)

*Trogoderma granarium* (the khapra beetle) (Fig. 35d)

A little oval, dark brown beetle, with a small head. The pest originated in India and spread to Europe in foodstuffs imported during the First World War. It has become established in Britain, mainly in maltings, where it feeds on barley. Under favourable conditions, the khapra beetle breeds prolifically and larvae appear in vast numbers on the surface of binned grain. The larvae tend to crowd into crevices where they are difficult to reach with insecticides.

*Life history.* The eggs are laid singly either scattered among grain or sometimes in the groove of the grain. The females lay about 40 or 50 eggs. The larvae are hairy, like those of all dermestids, being covered with two types of yellow-brown hair; long single ones and short barbed ones. The male moults four times and the female five times, and under adverse conditions, there are additional moults. They reach a final length of about 2.3 mm. Pupation occurs inside the last larval skin.

Some of the larvae develop normally, but others enter a diapause (see p. 57). These latter crawl into crevices and remain without further development until fresh warm malt or other foodstuff is placed nearby. Then they emerge and continue development. Diapausing larvae *may* remain quiescent for several years. Adults live about 2 weeks at 25°C.

*Speed of development.* At 30°C (86°F): E, 6·5; L, 24–30; P, 4·5; adult in cocoon, 2. At 25°C (77°F): E, 9·5; L, 38–47; P, 6; adult in cocoon, 3. All at 50% R.H.<sup>(19)</sup>

## BOSTRYCHOIDEA

### *Bostrychidae*

The bostrychids are a family of wood-borers.

*Rhizopertha dominica* ('Lesser grain borer') (Fig. 35h)

*Rhizopertha* is typical in form though somewhat anomalous in habit. It is a small active beetle, nearly cylindrical in shape, with a roughened, hump-like thorax. It is a serious pest of stored grain in India and other parts of the tropics. It is imported into Britain in cereals, which it damages even more seriously than the true weevils. However, all stages are normally killed by the cold of an English winter in unheated warehouses.

*Life history.* The females lay 300 to 500 eggs at the rate of up to 25 per day. The eggs are laid either loose or attached to grains. The larvae bore into the grains and feed on them from inside, until little is left but the husk. The older grubs are fleshy and with relatively small legs; they tend to lie curved in the form of a C. After 3 to 5 moults, pupation occurs inside the grain. The adults also feed on the cereal after emergence.

*Speed of development.* At 26°C (79°F): E, 12–18; L, 53; P, 6½. Total development (various temperatures), 24–133; average, 58.

### *Anobiidae*

Beetles of this family have a very pronounced hood-like thorax which nearly conceals the head when viewed from above. Several species are wood-boring pests (Chapter 14).

*Stegobium paniceum* (The 'biscuit beetle') (Fig. 35i)

This is a small beetle, reddish-brown in colour, with a dense covering of short yellowish hairs. It is a cosmopolitan pest of cereal products (especially farinaceous materials) and of various drugs, spices and beverage concentrates. In Britain it is the most common beetle pest of food to find its way into domestic larders. The American name, 'drug store beetle', indicates its propensity for breeding in dried vegetable matter of all kinds even in poisonous substances such as strychnine, belladonna or aconite. If infested goods are left for a long time on the shelves of a store, the beetles will tend to migrate and infest other commodities.

*Life history.* The female lays approximately 100 eggs, over a period of about 3 weeks, either in the actual foodstuff or in crevices nearby. The first-stage larva measures about  $\frac{1}{2} \times \frac{1}{8}$  mm; it is active and wanders about, readily crawling through small openings; so that they can often penetrate into uninfested packaged foodstuff. These larvae can survive as much as 8 days' starvation while searching for food. When a suitable breeding material has been found, the larva browses in it and becomes fat, sluggish and eventually incapable of moving about. There are four

moult in the larval stage and the fully grown grubs measure about 5 mm. Finally they construct a small cell of food particles cemented together with saliva and pupate inside it. The adults bite their way out and wander about, often far from the breeding site. They live for about 6 to 8 weeks but take no food. The sexes pair and after a few days, the females begin egg-laying.

*Speed of development.* At 24°C (75°F) and 45% R.H.: E, 9; L, 57; P, 9; adult in cocoon, 7-9; total, 83. At 19°C (66°F) and 37% R.H.: E, 14; L, 104; P, 15; adult in cocoon, 8-12; total, 143.<sup>(25)</sup>

*Lasioderma serricorne* (the 'cigarette beetle') (Fig. 35g)

The adult is somewhat like *Stegobium*, but smaller and rather more squat. It is a cosmopolitan pest and injurious wherever tobacco is grown, cured or manufactured. As well as tobacco, it infests various seeds and spices, oilcakes and locust beans, and has become, for example, a serious pest of stored cocoa in West Africa.

*Life history.* The females lay about 50 to 100 eggs, in crevices in the foodstuff. The young larva, like that of *Stegobium*, is active and can survive for a week without food. Later, however, it develops into a fleshy, sessile grub. After five or more moults, the larva builds a cell of fragments of food debris, in which it pupates. The adult beetles live for about 25 days at 30°C (86°F) or about 45 days at 20°C (68°F).

*Speed of development.* Although most records of *L. serricorne* relate to tobacco, it thrives better on many other commodities. The best studies of its bionomics were made on a colony reared on wheat-feed.<sup>(22)</sup> At 20°C (68°F): E, 21; L, 69; P, 12. At 25°C (77°F): E, 10; L, 28; P, 6. At 30°C (86°F): E, 6; L, 18; P, 4. All at 70% R.H. No development below 20°C or 40% R.H.

#### *Ptinidae* ('spider beetles')

This group is closely related to the Anobiidae. The larvae develop into similar fleshy, curved, sessile grubs and the adults have humped thoracic hoods. But most of the beetles have a waist-like constriction at the back of the thorax which, with their rather long legs, imparts the resemblance to spiders responsible for the common name.

#### *Ptinus*

The two most common species are distinguished as follows:

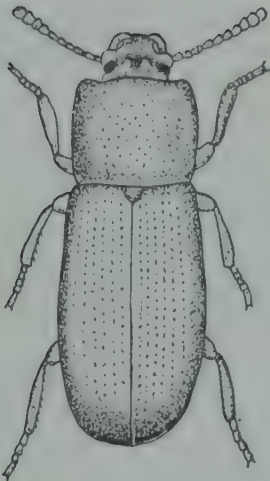
Elytra densely clothed in brown or golden-brown hairs so that striae and intervals are not distinct unless specimen is rubbed (Fig. 36f)

*P. tectus* ('Australian spider beetle')

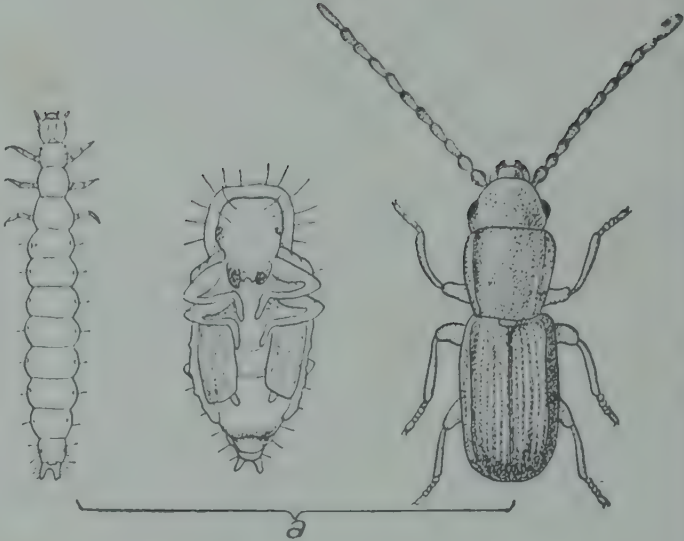
Elytra more sparsely hairy so that striae are always distinctly visible. Prothorax with a longitudinal, feebly oblique, dense cushion of paler hairs on each side near the base

*P. fur* ('white-marked spider beetle')

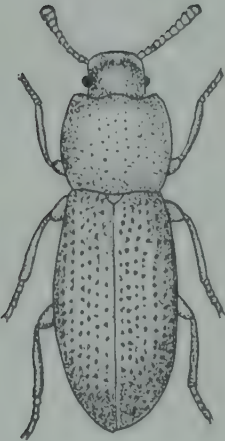
Both species are now cosmopolitan and *P. fur* has been widely known since the days of Linnaeus. *P. tectus*, on the other hand, has spread from Australia (? Tasmania) within the last half-century. It reached Europe about 1900. It is now the most widespread beetle pest in warehouses in Britain.



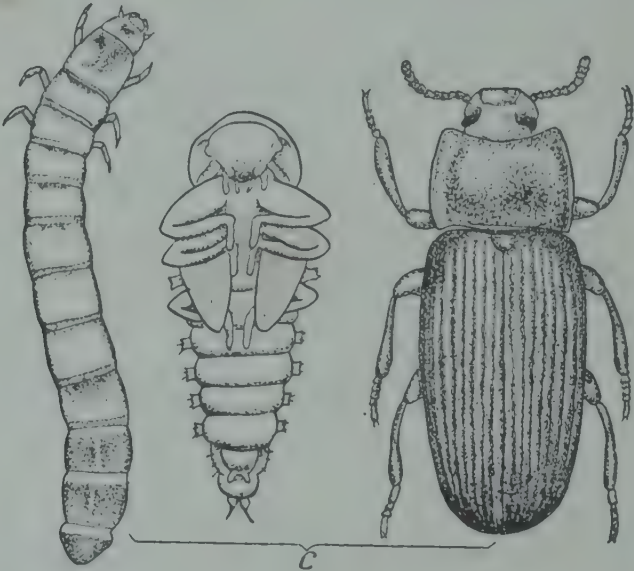
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a



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c

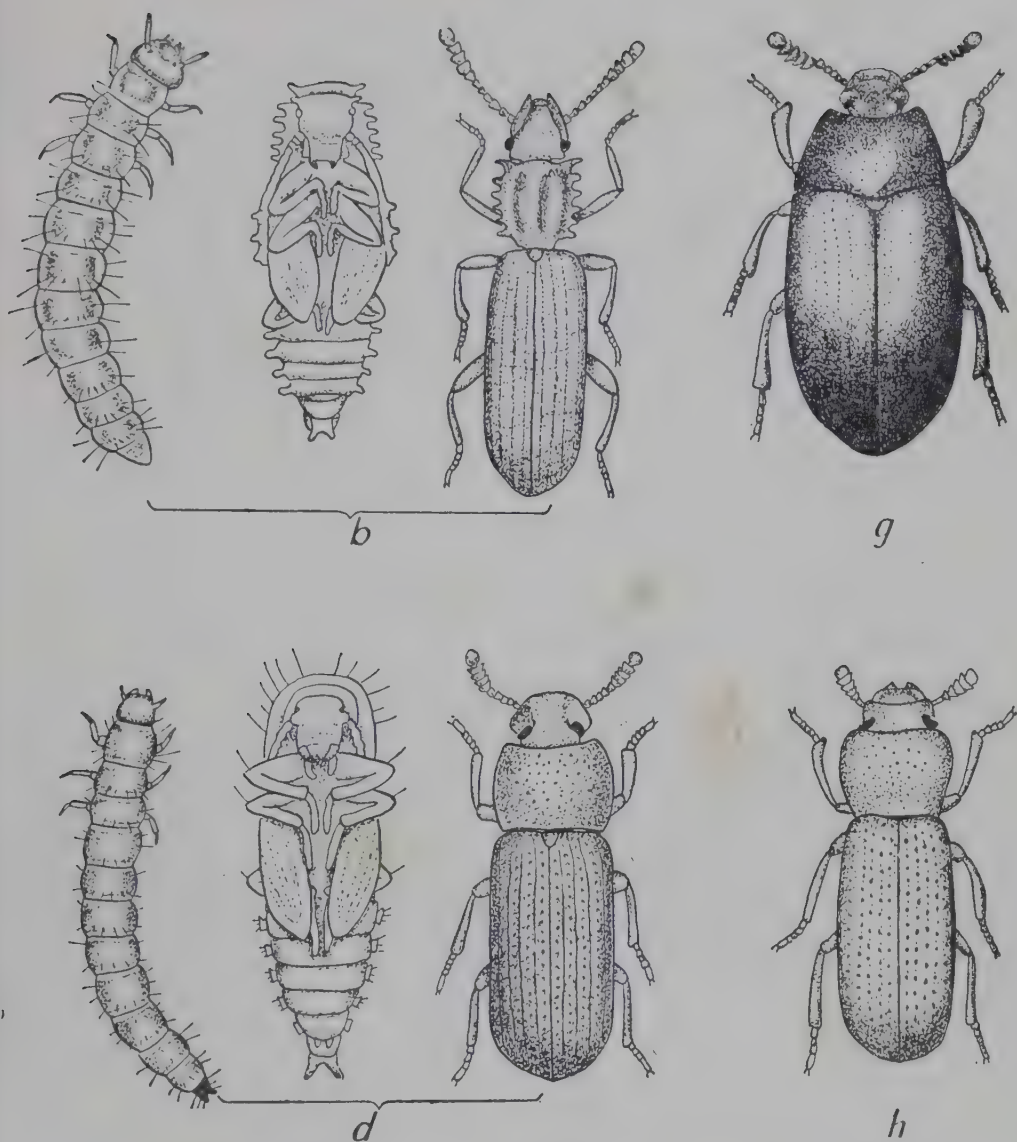
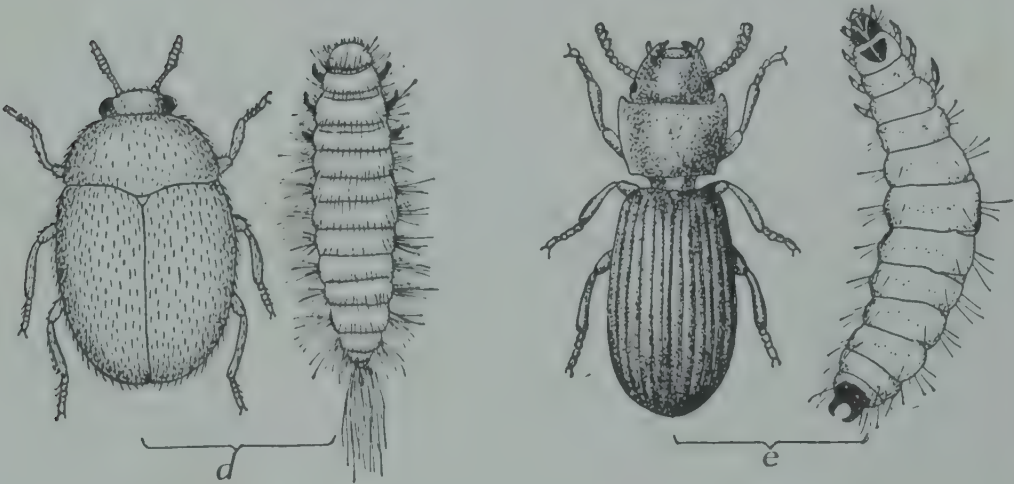
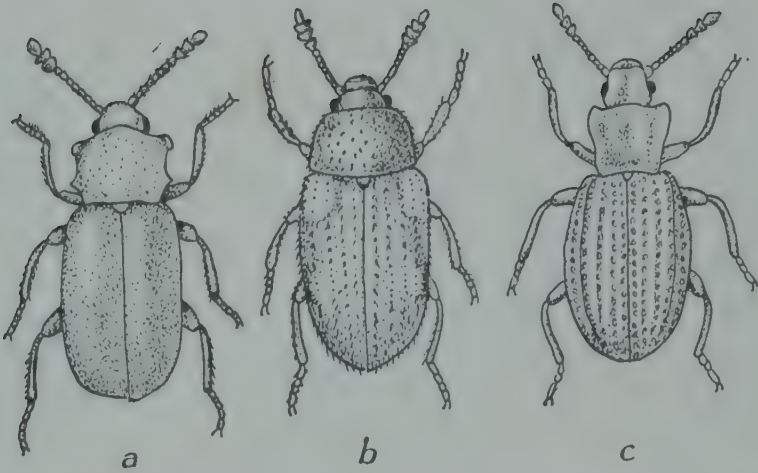


FIG. 34. Beetle pests of stored products. (a) *Cryptolestes ferrugineus*; (b) *Oryzaephilus surinamensis*; (c) *Tenebrio molitor*; (d) *Tribolium confusum*; (e) *Gnathocerus maxillosus*; (f) *Palorus ratzeburgi*; (g) *Alphitobius diaperinus*; (h) *Latheticus oryzae*. (a), (c), (e), (f), (g), (h) partly after Patton, *Insects, ticks, mites and venomous animals* (1931); (b) (d) after Chittenden, U.S. Dept. Agric. (1902) and (1897). (a) & (b)  $\times 15$ ; (c)  $\times 3$ ; (d)  $\times 10$ ; (e) (f) (g) & (h)  $\times 15$ .



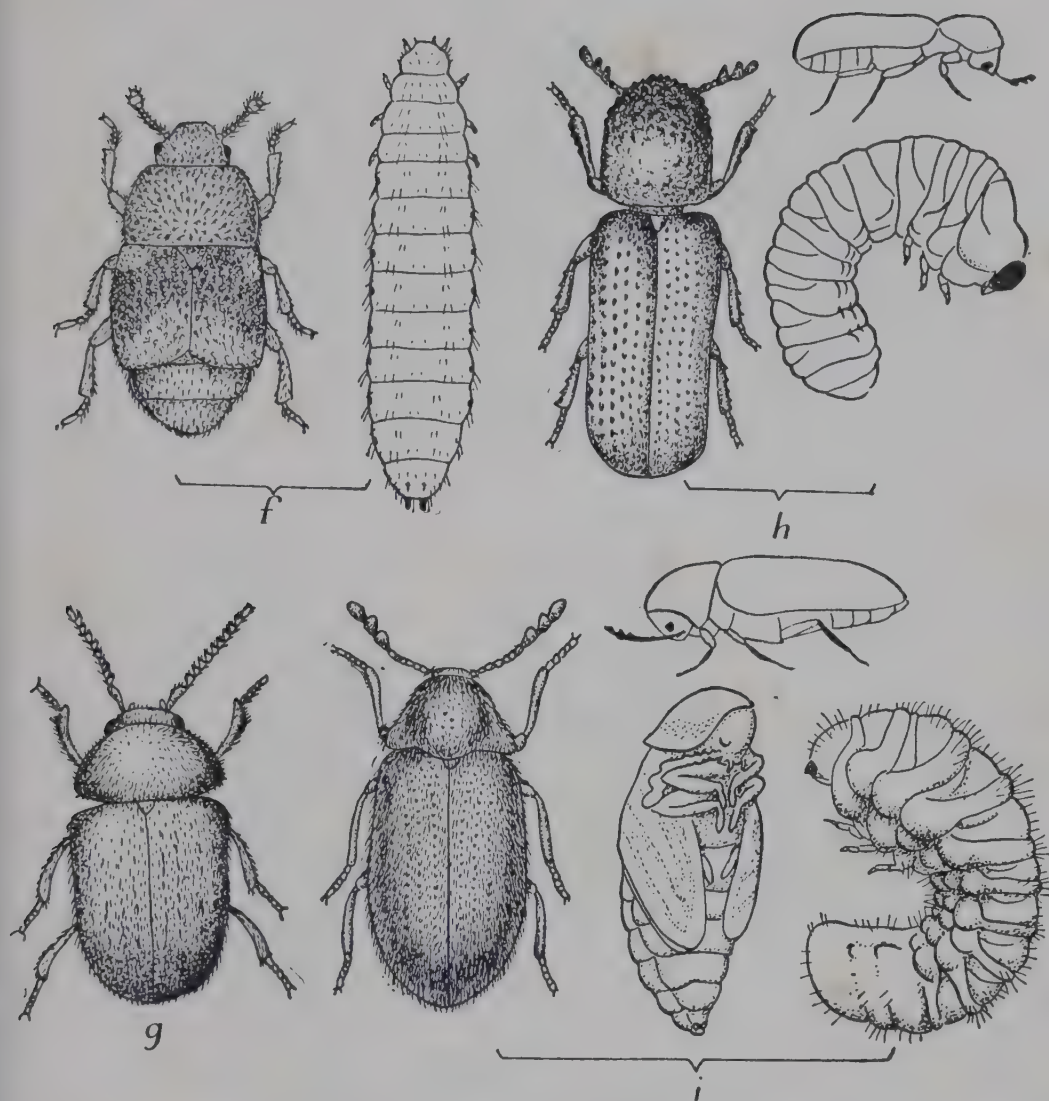
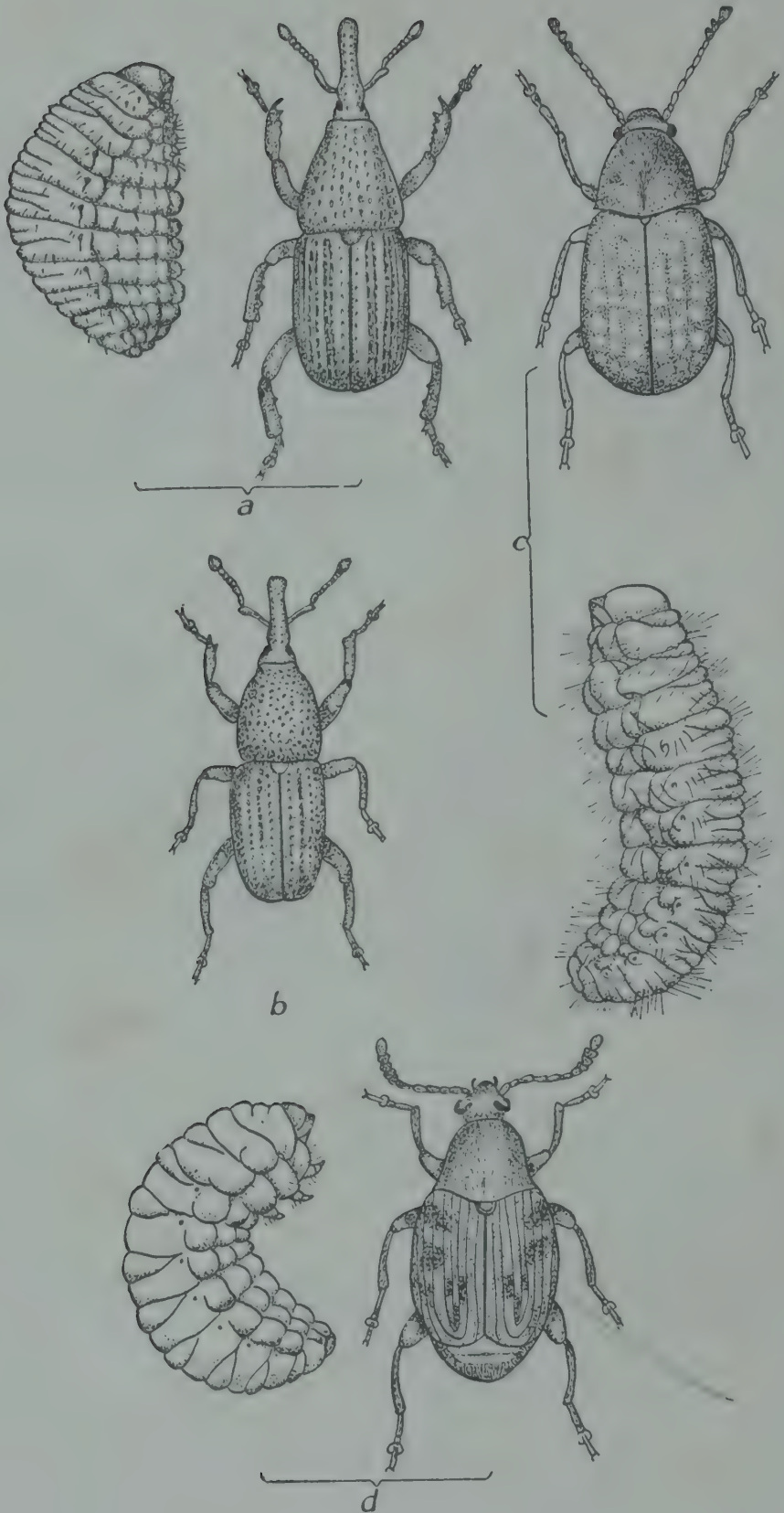


FIG. 35. Beetle pests of stored products. (a) *Cryptophagus acutangulus*; (b) *Mycetophagus quadriguttatus*; (c) *Enicmus minutus*; (d) *Trogoderma granarium*; (e) *Tenebroides mauritanicus*; (f) *Carpophilus hemipterus*; (g) *Lasioderma serricorne*; (h) *Rhizopertha dominica*; (i) *Stegobium paniceum*. (b) & (c) after Hinton, *Beetles of stored products*, Brit. Mus. (Nat. Hist.) 1943; (e) after Patton, l.c.; (f) after Kemper, *Z. Hyg. Zool.* **30**, 34; (g) after Bovingdon (1931), *Tobacco*, Aug. 1; (h) after Vayssiere and Lepesne. Remainder original. (a)  $\times 15$ ; (b)  $\times 12$ ; (c)  $\times 20$ ; (d)  $\times 15$ ; (e)  $\times 5$ ; (f) (g)  $\times 10$ ; (h)  $\times 15$ ; (i)  $\times 12$ .



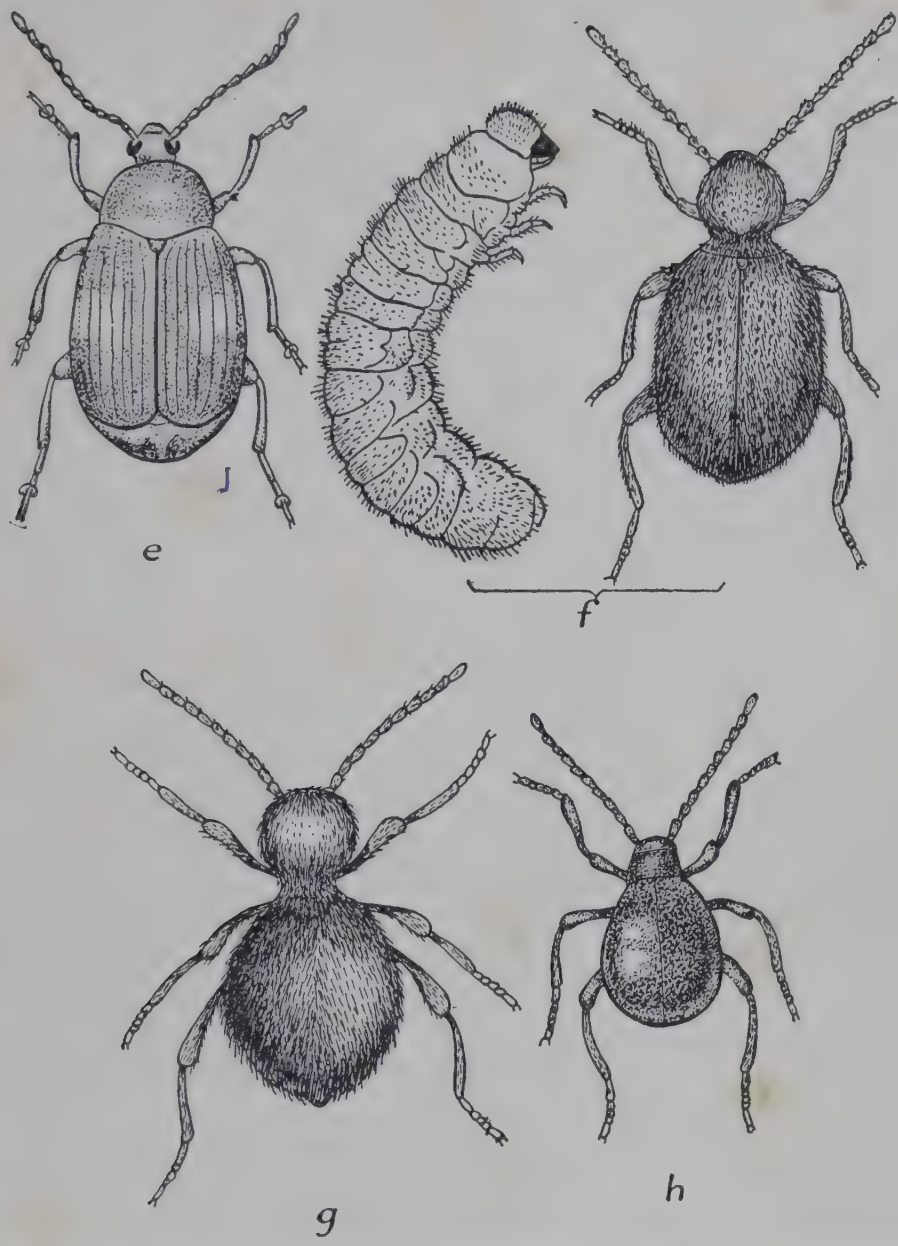


FIG. 36. Beetle pests of stored products. (a) *Sitophilus granarius*; (b) *Sitophilus oryzae*; (c) *Araecerus fasciculatus*; (d) *Acanthoscelides obtectus*; (e) *Zabrotes subfasciatus*; (f) *Ptinus tectus*; (g) *Niptus hololeucus*; (h) *Gibbium psylloides*. (All modified after Patton, l.c.) (a) (b) (c) (d)  $\times 10$ ; (e)  $\times 15$ ; (f)  $\times 10$ ; (g) (h)  $\times 7$ .

The larvae of *Ptinus* feed on all types of dry vegetable or animal matter. They have been recorded as pests of cereals, cereal products and spices. But they often live in stores and warehouses as scavengers of miscellaneous debris. Before pupation the larvae tend to bore holes into (and thus damage) various inedible things such as cardboard boxes, books, sacks and even wood.

*Life history.* About 100 or more eggs are laid by the female, either singly or in small batches at intervals of a few days. Oviposition continues for about 3 to 4 weeks at normal room temperatures. The eggs are sticky when laid and often adhere to various objects. The larvae grow into fleshy, helpless grubs like those of anobiids. After 4 or 5 moults, they spin a cocoon cell and pupate inside it. If they are infesting food in sacks or cardboard boxes, they often bore through and form the pupal cocoon outside. After emergence the adults rest for a considerable period in the pupal cell, sometimes as much as 3 weeks. The adults avoid light and are to some extent gregarious so that large numbers may be found resting in dark places near the food. At night they wander about to a considerable extent.

*Speed of development (P. tectus).* At 20–25°C (68–77°F): E, 3–16; L, 40 or more; P, 20–30; total, about 3½ months.<sup>(22a)</sup>

*Niptus hololeucus* ('golden spider beetle') (Fig. 36g)

This is a somewhat larger beetle, covered with long silky golden hairs and fine scales. It has been known in Britain since about 1836 when it was said to have been imported from Turkey. Since then it has become widely spread all over Europe.

The feeding habits resemble those of *Ptinus*, so that these beetles are not often important pests of stored food; but they sometimes damage cereals, cereal products, spices and drugs. More commonly, they feed on miscellaneous vegetable and animal remains (e.g. dead insects) and especially the debris in warehouses, cellars and ill-kept store rooms. The adults are sometimes very troublesome in houses from their habit of biting holes in various textiles (garments, carpets and bedding).

*Life history.* Similar to that of *Ptinus*. The adults can live as long as 250 days. They rest quietly in dark (and, preferably, moist) places during the day and wander about at night. They move about actively at temperatures down to 5.5°C.

*Speed of development.* At 15°C (59°F): E, 20–30; L, about 250; P, about 26. At 18–20°C (64–68°F): E, 11–20; L, about 150; P, 18–22.

*Gibbium psylloides* (Fig. 36h)

This beetle is shining and devoid of hairs or scales. It has a large rounded abdomen which gives it the appearance of a giant mite.

*Gibbium* has been recorded as a grain pest in India, but in Europe it tends, like *Ptinus* and *Niptus*, to be more of a scavenger and sometimes a nuisance. The adults have the same troublesome habit of biting holes in textiles.

*Life history.* Rather similar to *Ptinus* and *Niptus*. The adults are sluggish and long lived (up to 18½ months at 25°C; 77°F).

## CLEROIDEA

*Cleridae*

An extensive family of mostly tropical beetles. Many examples are finely coloured and beautiful.

*Necrobia rufipes* ('copra beetle')

This is a distinctive, shiny, bluish-green beetle with reddish legs. Practically cosmopolitan, it is not, however, very prevalent in Britain. It thrives best in dried meats, bones, copra, palm kernels and other oilseeds.

*Life history.* The eggs are laid on the food material and as many as 2000 have been laid by a female, though the average is only about 300. The larvae burrow in the food, having especial preference for fatty tissues: the larvae are sometimes predaceous, e.g. on cheese skippers (*Piophilidae casei*). They can survive 62 days without food. They moult 2 to 4 times and reach a length of 10 mm. Pupation occurs in a paper-like cocoon away from the greasy food. The adults have been observed to live 14 months.

*Speed of development.* At 25°C: total development 6 to 24 weeks according to the quality (fresh protein value) of the food.

*Trogositidae**Tenebroides mauritanicus* ('cadelle') (Fig. 35e)

The adult is fairly easily recognized by its distinctive shape, being a black, flattened beetle with a short 'waist' between thorax and abdomen. It is a widely distributed pest, being especially troublesome in flour mills, from which it is difficult to eradicate. It has also been found attacking cereals, cereal products, spices, nuts and dried fruit.

*Life history.* The female lays batches of 10 to 40 eggs at roughly fortnightly intervals. This continues for several months and as many as 1200 eggs have been reached, though the average is nearer 500. The eggs are laid in the larval foodstuff; for example, in the superficial layers of flour. The larvae grow from a length of 1½ to about 18 mm and moult at least 3 or 4 times (or up to 11 times under poor conditions). The mature larva excavates a hole in some solid material (wood, or cork) in which it pupates. This habit causes considerable damage to woodwork in grain stores, flour mills and railway wagons transporting grain. Furthermore, it provides shelter, not only for the cadelle, but for other grain pests. Many seemingly empty grain bins may actually contain a large nucleus of pests to reinfest new deliveries. Both adults and larvae have been stated to be predaceous, but this only occurs to a small extent. The adults may live as long as 21 months. They are resistant to starvation and have survived 52 days at 20°C and four months at 4–10°C without food.

*Speed of development.* At 21–22°C (70–71°F): E, 16; L, 232–282; P, 22–25. Under cool conditions, with a poor diet, the larval period may last up to 1248 days.

## CUCUJOIDEA

*Cucujidae*

These are small flattened beetles, many of which live under the bark of trees and some are predatory. A few species are grain feeders and have become pests of stored food.

*Cryptolestes* spp. (e.g. *C. ferrugineus*, 'rust-red grain beetle') (Fig. 34a)

The pest species are minute (about 2–3 mm long) and practically cosmopolitan. They are often scavengers of minor importance, but sometimes local damp foci encourage their proliferation and they may then spread through and spoil bulk foodstuffs. *C. pusillus* is often found in vast numbers associated with the rice weevil (p. 315).

*Life history.* The eggs are laid in crevices of grain or dropped loose among farinaceous materials. The larvae grow from about 0.4 to 4 mm in length, moulting about 4 times in the process. The larva forms itself a small cell of debris in which to pupate. Adults are recorded as living for 7 months.

*Speed of development.* Total, from 35 to 75 days, according to temperature and quality of the food.

*Silvanidae*

This is a small family closely related to the Cucujidae.

*Oryzaephilus surinamensis* ('saw-toothed grain beetle') (Fig. 34b)

*O. mercaptor* ('merchant grain beetle')

*O. surinamensis* was so described by Linnaeus because his specimens had been sent from Surinam. The common name refers to lateral serrations on the thorax. *O. mercator* is generally similar in appearance and habits. Both species are very small, active, brown insects, cosmopolitan in distribution.

*Products attacked* include cereals and cereal products, dried fruit and drugs. They are liable to be serious pests of packaged food and may spread throughout a grocery store, if left unchecked.

*Life history.* The eggs are laid in crevices in or near the food material. The females lay up to 400 eggs (average about 170) under warm conditions, but cease laying in cold weather. The larvae are yellowish with flecks of brown and a brown head. They grow from about 0.9 to 3.0 mm and moult 2 to 5 times. Any dried plant materials may be suitable as food, though the larvae probably cannot attack undamaged cereal grains. Pupation occurs in a little cell constructed of bits of food and other debris. The adults are rather long-lived; they average 6 to 10 months though as much as 3 years has been recorded.<sup>(37)</sup>

*Speed of development.* At 20–23°C (68–73°F): E, 8–17; L, 28–49; P, 6–21. Total development: at 20°C (68°F), 83–108. At 31°C (70°F), 68–76. At 27°C (80°F), 22–32.

*Ahasverus advena* ('foreign grain beetle') is similar in general size and appearance to *Oryzaephilus* except that each side of the thorax bears only one tooth, at the anterior corner. It probably feeds mainly on moulds and refuse.

*Nitidulidae*

*Carpophilus* spp. ('dried fruit beetles') (Fig. 35f)

The common species, *C. hemipterus*, has each elytron dark brown with a large and distinct, pale (usually yellow) spot at the apex and smaller spot at the angle of the base. Other species (with elytra unicolorous) are *C. dimidiatus* and *C. ligneus*.

*C. hemipterus* is a cosmopolitan pest which is particularly troublesome to the dried fruit industry in California. In Britain it is usually found in imported dried fruit, which is usually completely spoilt by the mess of frass and larval skins produced. Other products less commonly attacked include nuts, damaged grain and spices.

*Life history.* The eggs are laid on ripe fruit on the trees or after drying. The active first-stage larva feeds on the fruit pulp and grows eventually to a length of about 9 mm. The pupa lies naked in the food or nearby.

*Speed of development.* At 28°C (82°F) (summer in California): E, 2; L, 10; P, 7; pre-oviposition, 3; total, 22 days.

*Cryptophagidae. Cryptophagus* sp. (Fig. 35a)

*Mycetophagidae. Mycetophagus* etc. (Fig. 35b)

*Lathridiidae. Enicmus* sp. (Fig. 35c)

These are very small brown beetles (mostly 1–2 mm long) which live among vegetable debris, either as scavengers or feeding on moulds and fungi. They are not to any large extent food pests, but often they occur in warehouses, stores and domestic larders, especially under rather damp conditions. Hence they are sometimes recorded as contaminating various foodstuffs (see also pp. 411–412).

*Tenebrionidae*

This is a very large family, varying considerably in size and other characteristics. Most of the stored product pests are oval-oblong in shape, dark brown or black in colour and their larvae are all rather similar in appearance.

*Tenebrio* spp. (mealworm beetles) (Fig. 34c)

The two common species are most easily distinguished by the larvae. Those of *T. molitor* are shining yellow, while those of *T. obscurus* ('dark mealworm') are tinged with brown.

The mealworm beetles are among the largest of the beetle pests of food. The larval stages are the familiar mealworms used for feeding small animals and reptiles. Both larvae and adults feed on cereals and various cereal products; but they grow and proliferate rather slowly and, in spite of their size, do less damage than many smaller beetles. They thrive best in dark and rather damp situations and their presence is an indication of long neglect of cleaning. Both species are cosmopolitan.

*Life history.* The females have been observed to lay from 77 to 576 eggs, singly or in batches, as many as 40 being deposited in a day. The larvae, as already mentioned, are a bright yellowish colour shading to a yellowish brown at the ends of the body and along the intersegmental joints. They are practically omnivorous and will devour scraps of meat and the dead bodies of insects as well as the cereals that constitute their usual diet. They are very resistant to starvation and may live 6 to 9

months without food or moisture. After a varying number of moults (9–20) they reach a length of up to 28 mm. When about to pupate they wander away from the food and may be discovered in various unusual places. Often they may be found in bags or packages of other products than those actually infested. A few days before pupation, they become sluggish and often lie on one side in a slightly curved position. The pupae occur naked among the food mass. The adults, which tend to avoid the light, usually live about 2 or 3 months.

*Speed of development.* At 18–20°C (64–68°F): E, 10–12; L, 1–1½ years; P, about 20. At 25°C (77°F): L, 6–8 months; P, 9; total development, 280–630 days.

### *Blaps* spp. ('churchyard beetles')

These insects are not specifically food pests though they may occur in spilt or damaged food debris in sheds, warehouses and stores. The larvae should not be confused with those of the mealworm, which they greatly resemble. The last visible segment of the body bears a single upturned dark spine; whereas, in *Tenebrio* spp. there are two such spines.

### *Tribolium* spp. ('flour beetles')

1. Black or very dark brown (5–6 mm) *T. destructor* ('dark flour beetle')  
Brown (3–4.5 mm) (2)
2. Antennae with a distinct, moderately compact 3-segmented club. Eyes separated by much less than 2 diameters of an eye. No ridge present above the eye. *T. castaneum* ('rust-red flour beetle')

Antennae with a loose, indistinct 5- or 6-segmented club or without a club.

Eyes separated ventrally by a space equal to 3 diameters of an eye. A slight ridge evident above each eye (Fig. 34d) *T. confusum* ('confused flour beetle')

*Tribolium* is a cosmopolitan genus, the two most common species being *T. castaneum* and *T. confusum*; these are common and serious pests of cereal products, especially flour. They do not appear to be able to attack sound grain, but often add to the damage of primary grain pests. *Tribolium castaneum* is the most commonly intercepted insect on many kinds of imported food, being especially numerous on oilseed, oilcake and rice bran. *T. confusum* is less common and tends to be more restricted to cereal products.

*Life history.* The eggs are laid singly, from 2 to 10 per day, according to temperature, over a period of many months and reaching a total of about 450. Oviposition ceases below 15°C (59°F). The eggs are sticky when laid and become coated with food particles or other debris. The larvae grow from a length of about 1 mm to 5 mm, moulting from 5 to 11 times (usually about 7 or 8). The pupae lie naked in the food, gradually darkening before emergence of the adult. The adults feed on the same substance as the larvae. Under very warm conditions, *T. castaneum* adults readily fly; but those of *T. confusum* rarely do so. Males have been recorded as living about 600 days and females about 450. At 15°C (59°F) the larvae starve to death after some 50 days and the adults in half that time.

*Speed of development (T. confusum).* At 22°C (71°F): E, 14; L, 60; P, 17; total, 91. At 27°C (80°F): E, 6; L, 22; P, 9; total, 37.

*Gnathocerus cornutus* ('broad-horned flour beetle')

*G. maxillosus* (Fig. 34e) ('slender-horned flour beetle')

These beetles are slightly larger than *Tribolium*, being about 4 mm long, but generally similar in appearance. They can be easily distinguished, however, by the greatly enlarged mandibles of the males, curving outwards in front of the head (those of *G. cornutus* being broader, as the common names imply).

Cosmopolitan in distribution, these are mainly pests of flour and meal, though they also occur on grains.

*Development (G. cornutus).* 'In warm weather': E, 5; total, 8 weeks.

*Palorus ratzeburgi* ('small-eyed flour beetle') (Fig. 34f)

These are the smallest of the flour beetles (about 2.5 mm long). The antennae have no well-marked club. The thorax and head are wider, the legs more slender than *Tribolium*. Cosmopolitan; mainly a pest of ground cereals.

*Latheticus oryzae* ('long-headed flour beetle') (Fig. 34h)

The head is relatively larger than *Tribolium* and the antennae wedge-shaped. Pale yellow in colour. Length 2.3–3 mm. Cosmopolitan; mainly a pest of ground cereals.

*Alphitobius diaperinus* ('lesser meal-worm beetle') (Fig. 34g)

*A. laevigatus* ('black fungus beetle')

These beetles are distinctly larger than *Tribolium*, being about 6 mm long. They are black, more oval than oblong, with the back of the thorax strongly bi-sinuate.

They breed mainly in damp situations in grain or cereal products which are spoiled or are out of condition. The former is often found in large numbers in the deep litter of broiler houses.

#### CHRYSOMELOIDEA

##### *Bruchidae* ('pulse beetles')

The beetles of this family are mostly ovoid in shape and have characteristically abbreviated elytra which leave exposed the tip of the abdomen. They breed in leguminous seeds, which many attack in the pod in the field; others will breed in dried stored seeds. The following simplified key may help to distinguish some common genera.

- |  |                        |
|--|------------------------|
| 1. Hind tibiae with two movable spurs  | <i>Zabrotes</i>        |
| Hind tibiae with only fixed teeth  | (2)                    |
| 2. Lateral margin of thorax with a tooth near the middle. Hind legs always black | <i>Bruchus</i>         |
| Lateral margin of thorax without teeth. Hind legs variable                       | (3)                    |
| 3. Thorax conical, with straight sides. Hind femur with 2 teeth                  | <i>Callosobruchus</i>  |
| Thorax with sides convex. Hind femur with only 1 tooth                           | <i>Acanthoscelides</i> |

Species of *Bruchus* are field pests which lay their eggs on the developing pods in the fields. The larvae may, however, complete their development after harvest and emerge during storage. Peas or beans damaged by these beetles are useless for

processing or canning. *Bruchus pisorum* occurs in dried pea and *Bruchus ervi* in lentils. The other genera will breed in stored peas and beans, as well as in the field. *Acanthoscelides obtectus* (the 'American seed beetle', Fig. 36d), *Callosobruchus maculatus* and *C. chinensis* (the 'cowpea beetles') and *Zabrotes subfasciatus* (Fig. 36e) are common species.

*Life history* (in stored beans). The eggs are laid among the dried beans. The first-stage larvae are active with well-developed legs. They bore into the beans and eat them from inside. The second- and third-stage larvae grow to fat and sessile grubs. They pupate in small oval cells excavated immediately under the seedcoat so that the adults can escape easily. The adults live about a week at 35°C (95°F) or 3 to 4 weeks at 18°C (64°F), but do not feed.

*Speed of development.* At 18°C (64°F) – *C. maculatus*:<sup>(8)</sup> E, 21; L & P, 119. *Z. subfasciatus*: E, 7; L, 34; P, 12. At 35°C (95°F) – *C. maculatus*:<sup>(8)</sup> E, 4; L & P, 15. 'In Uganda' – *A. obtectus*: E, 5; L, 14–21; P, 5–6.

## CURCULIONOIDEA

### *Anthribidae*

This family is closely allied to the true weevils, but the adults do not have a distinct rostrum (or snout) and the antennae are not elbowed.

*Araecerus fasciculatus* ('coffee bean weevil') (Fig. 36c)

A small, robust dark-brown beetle, with the tip of the abdomen projecting behind the elytra. The first tarsal joint on each leg is as long as the remainder together.

Widely distributed in the tropics and sub-tropics, it is imported into warehouses and factories in Europe, but dies out in a cold winter. It occurs most commonly in nutmegs and cocoa beans.

*Life history.* The female lays eggs on cocoa beans (on the tree, in warm climates) and the larvae develop inside. The larvae become fleshy and legless in the older stages, like those of weevils, but they are somewhat more slender. There are 5 moults and pupation occurs in the seeds.

*Speed of development.* (In Java.) At 27°C (80°F): E, 6–7; L, 23–29; P, 7–8 total, 29–57.

### *Curculionidae* ('weevils')

The weevils are a large vegetarian family, easily recognized by the snout-like prolongation of the head between the eyes, which carries the mouthparts at the tip. The antennae are 'elbowed' with a long basal segment and the last 3 or 4 segments enlarged to form an oval club. The larvae, which feed inside various parts of plants, tend to be white, fleshy, sessile grubs, often curled into the form of a C.

#### *Sitophilus*

The common species may be distinguished as follows:

Prothorax with punctures distinctly oblong or oval-oblong. Hind wings absent  
Uniform chestnut-brown colour (Fig. 36a)

2.5–5 mm *S. granarius* ('grain weevil')

Prothorax very densely set with round or irregular punctures. Hind wings present. Elytra usually with four reddish spots (Fig. 36b)

2-3.5 mm *S. oryzae* ('rice weevil')

3-3.5 mm *S. zeamais* ('maize weevil')

*S. zeamais* is rather larger and more shiny in appearance than *S. oryzae*; but for certain distinction, the penis of the male must be examined by an expert. For many years they were thought to be races of *S. oryzae*, but they are now considered as valid species.

#### *Sitophilus granarius*<sup>(35)</sup>

This species is widely distributed in temperate and warm-temperate climates. It is imported from abroad, but can also breed freely in this country. Grain weevils attack all kinds of whole grain and some cereal products (e.g. macaroni). Being wingless, it is well adapted to life in stored food and does not attack grain in the field.

*Life history.* Before oviposition, the female bores a small hole in the food grain with her mouthparts, deposits the egg in it and then seals the hole with a drop of gum-like secretion. The larvae complete their development inside the grain. In a large seed like maize, several larvae can develop successfully; but only one can usually survive in a small grain of wheat or rice. The fleshy shape of the larva can be seen in Fig. 36a. There are three larval stages, after which pupation occurs in the grain. Adult life ranges from about 160-260 days at 20°C (68°F) to about 100-120 days at 27.5°C (81°F). The total number of eggs laid is not greatly dependent on temperature; but under warmer conditions they are laid more rapidly for a shorter time. Humidity, however, is important, considerably more being laid at 70-80% R.H. than at low humidities. Under optimum conditions, about 200 eggs are produced at the rate of 2 to 3 per day.

*Adverse conditions.* Breeding does not occur below 13°C (55°F) or above 35°C (95°F). The adults, however, can survive for over 100 days at 4.5°C (40°F) and the larvae for over 70 days. The adults normally feed on the grain, but can survive starvation for 65 days at 13°C or 19 days at 30°C. Normally they avoid light and often enter grains hollowed out by larvae; but if the infested grain is disturbed, they tend to come out and walk about excitedly on the top of the grain. If handled, they 'feign death' for a short time (i.e. they lie still with their legs pressed close to the body).

*Speed of development.* At 18°C (64°F): E, 10.5; L, 55. At 20°C (68°F): E, 8; L, 40. At 25°C (77°F): E, 4; L, 27. At 27-28°C (80-82°F): P, 7.5. *Total development:* at 14-16°C (57-61°F), 113; at 23.5°C (74°F), 38; at 27°C (80°F), 29; at 30°C (86°F), 26.

#### *Sitophilus zeamais*<sup>(13, 46, 52)</sup>

##### *Sitophilus oryzae*

Both species are widely distributed in the tropics and are common pests on grain imported into Britain. According to German authors, *S. zeamais* has been common for some years on maize from the River Plate and accordingly was known as the

La-Plata maize beetle. This species is more common on maize, while *S. oryzae* is most prevalent on wheat and rice. Laboratory experiments show that from a mixed colony on maize, *S. oryzae* dies out (in 17 to 34 months); while *S. zeamais* dies out from a mixed colony on wheat (in 12 to 24 months).

The maize weevil has a preference for feeding on and laying eggs on maize rather than wheat, while the reverse is true of the rice weevil. Egg-laying preferences, however, are largely determined by the grain on which they are reared; but wheat has a stronger inducing effect than maize in both species.

Both forms can fly, in very warm weather (30°C), and the maize weevil can lay eggs on maize cobs in the field. The rice weevil is more sluggish, however, and is virtually restricted to breeding in stored grain.

*Life history.* The life history of both species, and many of their habits, resemble those of *S. granarius*. The number of eggs laid by the females are greater at 70% R.H. than at 50% R.H. Softer grains (e.g. wheat) allow more eggs to be laid than hard ones (rice). On the same grain (wheat), rice weevils laid an average of 148 eggs, as compared to the maize weevil's 217 (in 12 to 14 weeks at 25°C). At 20°C, about the same number of eggs were laid over 24 to 32 weeks.

*Speed of development.* Total development (of *C. oryzae*) at 16–18°C (61–64°F), 3 months; at 22–23°C (71–73°F), 2 months; at 27–28°C (80–82°F), 1 month. The maize weevil is slightly quicker. Thus, at 20°C (68°F), total for *S. oryzae* is 48–53 days, for *S. zeamais* 44–48 days.

## II · MOTHS (Lepidoptera)

### (a) Distinctive characters

The moths and butterflies are the best known and most easily recognized of all insects, but the species which attack stored products are rather inconspicuous representatives of the order. They are small and devoid of striking colours, the adults being mostly buff or greyish in tone and the larvae cream-coloured with brown markings. About 35 different species have been recorded from stored products in Britain, but many of these are comparatively rare. Most of them belong to two groups of families:

Pyralidoidea (dried fruit moths, flour moths, etc.)

Tinaeoidea (clothes moths and house moths)

### *Identification of moth pests of food*

Keys are provided (Appendix, p. 448) to distinguish the dozen or so species of moths most likely to be found in domestic infestations. Since, in many cases, the larvae only will be present, a separate key for larvae is given. These keys may be found rather difficult to use in the absence of entomological training, though they have been simplified as much as possible (p. 452).

### (b) Occurrence and life histories of various pests

The details given in this section correspond to those given for the beetles (see p. 299) except that, as the keys provided are more full, no descriptive matter is included.

## PYRALIDOIDEA

This is a very large assemblage of small to medium-sized moths comprising about a dozen, closely related families.

*Pyralidae*

Mainly a tropical group.

*Pyralis farinalis* (the meal moth) (Fig. 57k)

This relatively large moth is a minor pest of grain products and other stored vegetable matter (for example, hay, especially from clover and lucerne). It is cosmopolitan.

*Life history.* The eggs are laid in small clusters on the food material to a total of 120 to 160. The larvae live in long silken tubes of their own silk, sometimes several together. They reach a final length of 12 to 14 mm and pupate in a cocoon which incorporates particles of the food debris.

*Speed of development.* There are usually two generations per year.

*Galeriidae*

A small but widely distributed family of which the best-known species is probably *Galleria mellonella*, the 'honeycomb moth', which is a destructive pest of bee hives.

*Corcyra cephalonica* (the 'rice moth') (Fig. 57n)

Primarily a tropical insect, this is often imported into temperate regions with foodstuffs; but in northern countries it can only survive the winter in heated store rooms. The larvae are pests of grain (especially rice), grain products, oilseeds and oilseed products, beverage concentrates, nuts, dried fruit and spices.

*Life history.* About 120 to 160 eggs are laid in or near the larval food. The larvae meander over the food spinning a copious and strong webbing. The pupal cocoon is thick, strong and dense white and easily distinguished from the more transparent greyish cocoons of *Ephestia elutella*.

*Speed of development.* Under 'favourable conditions': L, 15-20; P, 7-10. Usually, however, only one generation a year in northern Europe.

*Paralipsa gularis* (Fig. 57e)

This moth has become a pest in Europe since about 1930. It breeds mainly in nuts and dried fruit and may cause considerable losses.

*Life history.* About 150 to 250 eggs are laid. The larva grows to a length of 20 to 30 mm and pupates in a rather dense, strong cocoon. The cocoons are formed in corners or crevices, or else many may be spun close together.

*Speed of development.* At 30°C (86°F): E, 4-5; L, ?; P, 20-115.

*Phycitidae*

This large group includes a few species which are the most serious lepidopterous pests of stored products.

*Plodia interpunctella* ('Indian-meal moth') (Figs. 37*b* & 57*d*)

This important pest is cosmopolitan but it is primarily a nuisance in areas where there is a large fruit-drying industry (e.g. California, Mediterranean, Australia). Dried fruit and nuts are principally attacked while maize, chocolates, cereal products and various seeds and drugs also suffer. Grubs which are overlooked can spoil a whole packet of dried fruit. Apart from the actual damage by feeding, the frass and webbing are unsightly.

*Life history.* The females exercise some choice in the type of fruit upon which they oviposit. Dry and shrivelled as well as very sticky fruits are avoided. Also, certain treatments and handling processes in the industry render the fruit more or less attractive. The number of eggs laid depends on the food of the mother in her larval life; the maximum observed was over 500. The larva readily feeds on fruit tissues and grows to a length of 12 mm and a breadth of about 1.75 mm (i.e. relatively slimmer than *Anagasta*). There are about 4 to 7 moults. The pupa, which measures about 7 mm, is formed in a fairly thick white cocoon. The adults emerge and mate and, in large fruit stores, continue to proliferate the infestation.

*Speed of development.* E at 20°C (68°F), 8; at 25°C (77°F), 4; at 30°C (86°F), 2; L (depends on food as well as temperature); P, 12–43 according to temperature. Shortest total development (at 25°C; 77°F), 35. But normally the larval stage is greatly prolonged by the winter in unheated store rooms. There are 1 or 2 generations per year.<sup>(22)</sup>

*Anagasta kuhniella* ('Mediterranean flour moth') (Fig. 57*i*)

In spite of the common name of this pest, it seems likely that its original home was Central America. It began to be widely dispersed by commerce about 1880 when roller milling was replacing grindstone milling; and it has since become cosmopolitan. The foodstuffs most frequently infested by this moth are ground cereal products and ground nuts or seeds or spices. It is a serious pest in flour mills, where its copious web interferes with milling. To some extent dried fruits are also attacked. Although it may occur in a wide variety of food substances, some of them are more favourable than others. For example, the larvae grow twice as quickly on rolled oats as they do on chocolate. They cannot develop on pure starch or gluten since they require food containing vitamins A and B (but not C).

*Life history.* The female lays about 200 eggs on the average though as many as 500 has been recorded. The elliptical white eggs measure 0.6 × 0.3 mm; they are dirty white in colour and often stuck to various objects by a sticky secretion.

The newly hatched larvae measure 1 to 1½ mm and grow to a length of 15 to 19 mm after undergoing 3 to 5 moults. They begin spinning silk at once and cover much food with webbing in the course of their lives. When fully grown, they become restless and wander away from the food. Finally they choose a dark corner for pupation which a proportion of them undergo without spinning a cocoon. The normal cocoon is formed of a thick outer layer and a thin inner one with a head cover over the emergence hole.

The adults rest in shady corners in the daytime and fly about at dusk or at night. If they are disturbed during the day, they fly off with a characteristic zig-zag flight.

Pairing can occur immediately after emergence and it lasts a long time (usually 12–15 hours). At normal room temperatures, the females begin egg-laying about half a day later and continue for about 11 days.

*Speed of development.* At 17°C (62°F): E, 8; L, 128; P, 16. At 18–20°C (64–68°F): E, 11; L, 56–70; P, 17–20. At 30°C (86°F): E, 3; L, 29; P, 7–10. At 18–20°C (64–68°F) there may be 4 generations per year, but in unheated store rooms there are not more than 3.<sup>(22)</sup>

*Ephestia elutella* ('the warehouse moth' (Figs. 37a & 57l)

This moth is widely distributed in temperate parts of the world; elsewhere its place is taken by its close ally, *Cadra cautella*, the tropical warehouse moth.

In Britain *E. elutella* can be a serious pest of cocoa beans and chocolate confectionery, of dried fruit and nuts. Manufacturers may suffer as the result of the depredations of this pest not only directly, but also by loss of reputation if pests are discovered in the finished product by the consumer. A number of other substances liable to infestation by this pest include tobacco, wheat or other grain stored in bulk, oilseeds, oilseed products or manufactured animal feeding stuffs.

It is seldom imported except on products from other temperate areas; the insect which is found on cocoa beans on arrival in Britain is *Cadra cautella*: during storage this dies out and is replaced by *Ephestia elutella*.

#### TINEOIDEA

##### *Tineidae*

These small moths breed in a wide variety of dry animal and vegetable matter. They are principally important for damaging woollen garments, furs, stuffed furniture and skins and are dealt with more fully as 'fabric pests' in Chapter 13. Several species will, however, breed quite successfully in food products, notably farinaceous materials and dried meats and spices.

*Nemapogon granella* (the 'corn moth') (Fig. 57h)

This is one of the most common tineids to occur in grain and grain products. It is widely distributed in Europe and has spread as far as North America and Japan.

*Life history.* Up to about 100 minute white eggs are laid by the females, often among grains of stored corn. The larvae wander over the food, feeding and spinning silken trails. They grow to a length of about 7 to 10 mm and, just before pupation, tend to wander away from the food and pupate in some dry crevice (e.g. between floor-boards). Sometimes, however, they pupate inside corn grains which have been eaten away till they are hollow. The adults, like the larvae, avoid bright light and mainly fly at dusk and at night.

*Speed of development.* Under 'normal conditions': E, 10–14; L, 2–4 months; P, 14–21. In northern Europe usually 1 generation per year (overwintering as mature larvae).

*Gelechiidae*

*Sitotroga cerealella* (the 'Angoumois grain moth') (Figs. 37e & 57b, c)

This pest is possibly of European origin, for a severe attack in France was recorded as long ago as 1671; or it may have been introduced from America. Its common name is associated with the province of Angoumois in France, but the pest is now widespread, though the pest cannot develop in the British climate. It is an important pest of stored grain of various kinds.

*Life history.* The eggs are laid, preferably soon after harvesting, on rye, maize, wheat or oats. The larvae burrow into the grains and develop inside. They become rather squat with very short legs, but always remain small, so that several may develop in a single large grain. They pupate inside the grain under a very thin cover which the adult pushes aside when it emerges. The adults do not feed, but mate and the females soon begin egg-laying.

*Speed of development.* E, 3-14. L at 20°C (68°F), 16; at 30°C (86°F), 10. P, at 15°C (59°F), 40; at 30°C (86°F), 7. Total, at 14°C (57°F), 115-118; at 21-26°C (70-79°F), about 42.

*Oecophoridae*

*Endrosis sarcitrella* ('white shouldered house moth') (Fig. 57o)

*Hofmannophila pseudospretella* ('brown house moth') (Figs. 37c & 57g)

These two moths are cosmopolitan and in Britain they breed out of doors as well as in houses and sheds. They will infest stored grains (especially if damaged) and also various grain products. They are often quite troublesome in outhouses where poultry food is kept, especially if it gets somewhat damp. In rooms of dwelling houses, where cleaning measures are somewhat neglected, *Hofmannophila* will also breed in debris under linoleum or carpets and may cause damage to the latter.

The life histories and bionomics are described in Chapter 13 (p. 354).

*Life history.* Eggs may be laid in cacao beans in warehouses in Britain, from late May to the end of July. Up to 260 eggs have been recorded as laid by a single female, in batches. The larvae gnaw their way into cacao beans and continue feeding inside, producing a mess of frass stuck together with silk threads, which often protrudes from a hole in the bean. When they are fully grown, the larvae measure about 11 to 12½ mm in length. They become restless, leave the food and wander about for 1 to 3 days. They tend to move upwards, yet they avoid the light, so that they collect in the darker corners of the walls and ceiling. Finally, they spin rather thin, greyish-white cocoons in corners and crevices. They remain in diapause as larvae until May the following year, when they pupate. The adults, like those of *A. kuhniella*, are able to take liquid food, but seldom do so. At normal room temperatures they live 2 to 3 weeks and at 25°C about 9 days. They fly about mainly at dusk and dawn, mate soon after emergence and the females begin to lay eggs a day later. Most of the eggs are laid in the first 4 days of adult life.

*Speed of development.* E at 20-24°C (68-75°F), 6; at 25-27°C (77-82°F), 4; at 28.5°C (83°F), 3; L, ?; P at 18-20°C (64-68°F), 16-19; at 22-24°C (71-75°F),

14; at 26°C (79°F), 10. Total, at ordinary room temperatures, 82–206. At 26°C (79°F) (on tobacco), 60–100 (majority).<sup>(26)</sup>

*Cadra cautella* (the 'tropical warehouse moth') (Fig. 57f)

This moth, widely distributed outside temperate areas, attacks almost any stored commodity except tobacco and animal products. It is the second most common insect found on imported food cargoes. It is an important pest of dried fruit, nuts, oilseeds and oilcakes. It is an important problem of the dried fruit industry in Australia, California and the Mediterranean. In the former countries it is perhaps less serious than *Plodia*.

*Life history.* The female lays eggs on fruit which is somewhat drier than that chosen by *Plodia*. Figs and dates are frequently attacked and also sultanas and other fruit. The course of the life history has not been carefully studied, but is probably similar to that of *Ephestia* and *Anagaster*. The larvae pupate close to the food and the cocoon is very similar to that of *Plodia*. *C. cautella* seems unable to survive the winter in unheated rooms in Britain.

### (c) Importance of beetle and moth pests of food

#### (i) Types of damage caused by infestation<sup>(9, 10, 11)</sup>

Insect pests in stored food consume it and, in heavy infestations, their depredations are detectable as actual loss of weight. Some pests tend to feed on the more nutritious part of the food (e.g. *Ephestia elutella* larvae select the germ of the wheat) and the loss of nutritive value due to infestation is therefore greater than the actual loss of weight.

A very troublesome consequence of infestation of bulk grain is heating.<sup>(33)</sup> Insects, though cold-blooded animals, produce a certain amount of heat as a result of their respiration. Normally, this rapidly dissipates; but grain is such a poor conductor of heat that pockets of infestation in a large store tend to become warm. This warmth accelerates the respiration and proliferation of the insects, so that the heating of such 'hot spots' is a kind of chain reaction.

Grain heating begins in small spots but, if unchecked, may spread throughout the whole bulk. Insect grubs which bore in the grains (*Sitophilus*, *Rhizopertha*, *Sitotroga*) are eventually killed by the heat produced; but other, more mobile larvae (*Cryptolestes*, *Oryzaephilus*) gradually move outwards as the temperature rises.

Associated with this heating is a movement of moisture, from the infestation centres to the top of the grain, or to other cooler regions. This is due to warm air at the heating centre, absorbing moisture from the grain, rising by convection and depositing the moisture by condensation. The damp regions thus caused are readily attacked by moulds and become caked by them. In some cases the grain begins to sprout.

The damage to grain by heating may comprise loss of germinative capacity in grain for seed or malting and spoiling of the baking quality of wheat. The encouragement of moulds will cause mustiness.

Apart from heating of grain, other special troubles may arise in infestations of bulk foodstuffs. Thus, moth infestations of flour mills cause clogging of machinery

by their webbing. Several beetle pests tend to bore holes in woodwork structures or in various packages.

On a small scale, problems of pest infestation are mainly consumer reactions of disgust at the tainting and spoilt appearance of packaged food.

(ii) *Losses due to infestation of stored food*<sup>(45, 58)</sup>

Enormous quantities of stored foodstuff are destroyed by insects throughout the world; estimates range from 5 to 10%, quantities greater than the total amount involved in actual trade. Most of these losses, however, occur in tropical countries, where food is stored under primitive conditions, and half the crop may be destroyed by pests before the next harvest. It would be quite wrong, therefore, to expect the overall world figure of losses to apply, with any accuracy, to this country. On the other hand, the standards of hygiene in Britain are such that comparatively minor contamination of food can cause complaints or rejection of goods. Consequently, the financial losses are out of proportion to the degree of infestation. This situation is maintained by two kinds of purchaser. (1) The rights of the private consumer in Britain are protected by the Food and Drugs Act and the Food Hygiene Regulations and sale of infested food may result in prosecution by a local authority. Generally speaking, however, reputable firms selling branded goods are most anxious to avoid loss of reputation by such an occurrence, irrespective of legal action. (2) Other important purchasers, who maintain high standards, are meticulous foreign markets for our manufactured foods. The American Food, Drug and Cosmetics Act, for example, imposes stringent regulations on imported foods, so that the presence of even parts of dead insects can cause refusal.

(iii) *Nature of the problem in Britain*<sup>(3, 11, 12)</sup>

Food infestation in Britain has certain distinctive aspects due to our cool temperate climate, with relatively few indigenous pests, and our enormous foodstuff imports. Much of our trouble results from a continual stream of insect pests, imported with the various products. Eventually, of course, the actual structures of the transporting ships and also the storage warehouses tend to become infested with insects. This leads to additional complications due to the possibilities of cross-infestation from one consignment of goods to another. The permanence of such infestations depends on the adaptability of the insects, one of the most important aspects of which is cold-hardiness, to survive our winter. In this respect, some of the pests mentioned may be grouped as follows:

PESTS SURVIVING THE BRITISH WINTER (without special protection):

Beetles: *Sitophilus granarius*, *Oryzaephilus surinamensis*, *Cryptolestes ferrugineus*, *Ptinus tectus*, *Stegobium paniceum*, *Tenebrioides mauritanicus*, *Tenebrio* spp. and *Dermestes* spp.

Moths: *Ephestia elutella*, *Anagasta kuhniella*, *Plodia interpunctella*.

PESTS SURVIVING MILD WINTERS:

Beetles: *Sitophilus oryzae*, *S. zea-mais*, *Lasioderma serricorne*.

Moths: *Cadra cautella*.

PESTS NOT SURVIVING THE WINTER, unless protected or warmed in some way:

Beetles: *Tribolium* spp., *Rhizopertha dominica* and *Carpophilus hemipterus*,  
*Araecerus fasciculatus*, *Necrobia rufipes*.

Moths: *Sitotroga cerealella*.

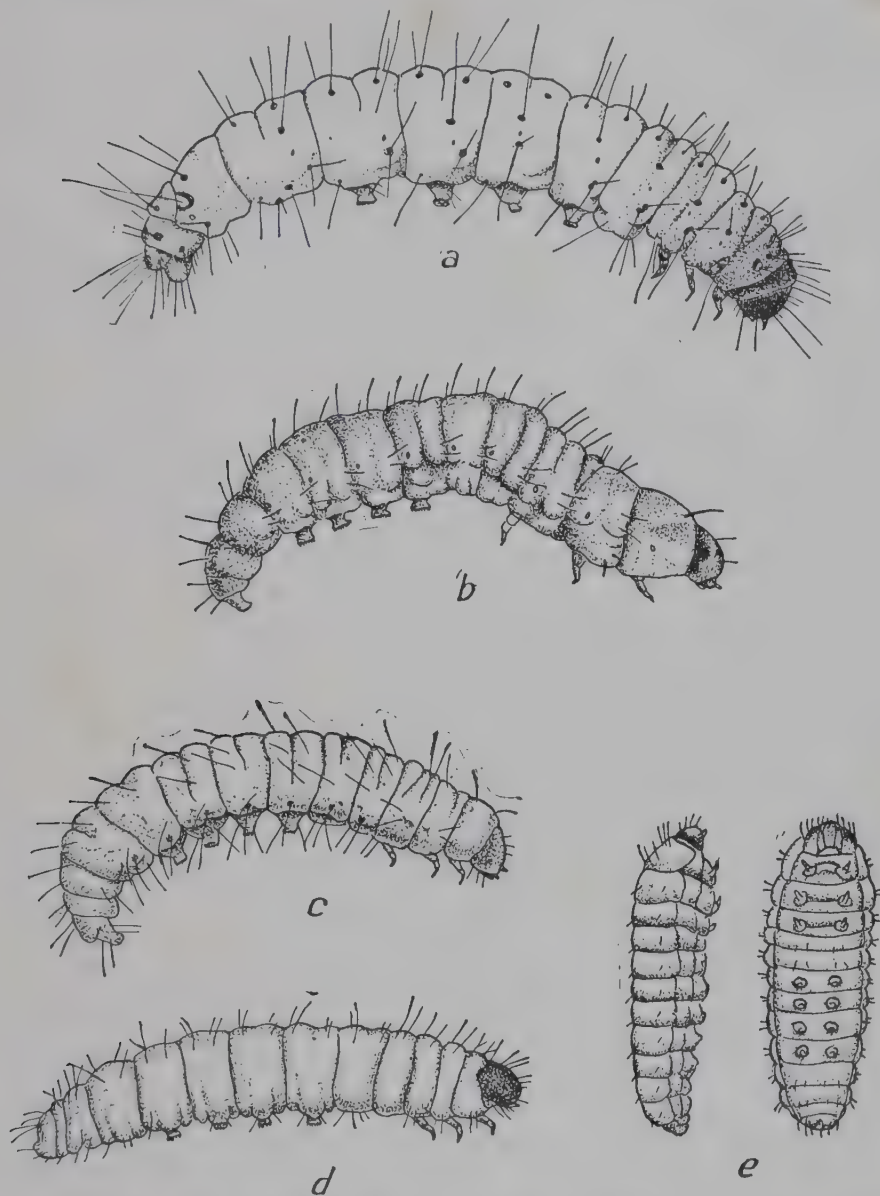


FIG. 37. Larvae of stored product moths. (a) *Ephestia elutella*; (b) *Plodia interpunctella*; (c) *Hofmannophila pseudospretella*; (d) *Tineola bisselliella*; (e) *Sitotroga cerealella*. (a) after Bovingdon; (b) after U.S. Dept. Agric. Fmrs Bull. 1260; (c), (d) & (e) after Patton (l.c.). Approx.  $\times 5$ .

#### (d) Control of beetle and moth pests of stored products

##### (i) Infestations in ships, barges, warehouses, mills and factories<sup>(12)</sup>

The numerous problems in the control of insect pests of food in bulk storage are largely beyond the scope of this book. A great deal of effort is expended in endeavouring to provide the consumer with products free of insect pests. This work is

co-ordinated by the Infestation Control Laboratory of the Ministry of Agriculture, Fisheries and Food.

The subject, which can only be outlined here, must be considered in several stages. The first problem is the importation of infested cargoes from abroad. Attempts are being made, through international co-operation, to reduce infestation levels in the exporting countries; this will eventually benefit us, by reducing the scale of pest importation. During the voyage (especially if there is a long journey through the tropics) an original infestation will proliferate; it may also spread and contaminate other cargo.

On arrival, the cargo may be fumigated after discharge into barges, or on shore. The ship's holds may be treated with smoke insecticides, contact sprays or in serious cases by fumigation. The gas used most commonly is methyl bromide. Bagged or boxed goods in warehouses may be fumigated under gas-proof sheets. Grain or oilseeds in bulk may be treated by application of liquid fumigants on the surface or by circulation of methyl bromide in specially equipped silo bins.

Contact insecticides have a useful place, although they have not played such an important part in the control of storage pests as of those of medical importance, since storage pests are often deep in commodities where the contact insecticides cannot reach. They are used in several ways. They are applied as smokes or sprays (emulsions or suspensions) to the surfaces of warehouse rooms or bins, or holds of ships, barges, etc., to kill residual infestations. They are applied to the surface of containers of commodities (e.g. dried fruit) to protect them from attack or to prevent insects already there from spreading elsewhere. Or they are mixed with the food to kill insects already present or to protect it from attack. Very few substances can be used safely this way and in practice only pyrethrins (plus synergist) and malathion are employed. Dusts have been largely replaced by emulsions and effective protection against the saw-toothed grain beetle and other grain pests has been achieved with as little as 8 parts per million of malathion applied to wheat. Such dosages do not cause tainting.<sup>(42)</sup>

Control of flying insects may be obtained by hanging in warehouse rooms plastic strips impregnated with dichlorvos. This is given off slowly and a low concentration of insecticide is maintained in the air continuously. This low concentrate is lethal to some insects but not to man.

Considerable improvement can be effected by good store keeping and cleanliness. Goods must be stacked so as to allow access to all sacks or boxes. Deliveries should be used in rotation. All spillage should be removed, preferably by use of industrial vacuum cleaners.

When warehouses are empty, a special attempt at cleaning should be made to reduce sources of food for residual insects. At this stage it may be feasible to spray walls and floors with one of the safer contact insecticides (e.g. malathion). Residual insect populations in empty sacks should be destroyed by fumigation, before the sacks are re-used.<sup>(31)</sup>

(ii) *Infestation of farm-stored grain*<sup>(39)</sup>

Grain is often stored on farms before sale for malting, for animal fodder on the farm, or for seed; and during the period of storage may suffer from attack by insects. Among the more common beetle pests on British farms are *Sitophilus granarius*, *Oryzaephilus surinamensis* and *Cryptolestes ferrugineus*. To prevent or reduce losses from this source, the first essential is good storage conditions in a damp-proof building. Regular inspection and cleaning are desirable and this entails storage in a manner allowing access.

Grain bought from outside sources should not be stored alongside farm-grown seed; this will reduce the risks of cross-infestation. So far as possible, all stocks should be used in rotation to prevent accumulation of very old stocks.

Where infestations have developed, fumigation is convenient to destroy the pests. Small quantities can be treated in a metal bin (see p. 137); larger amounts may be fumigated under gas-proof sheets.

Contact insecticides such as *gamma* BHC and malathion may be used for treatment of walls, bins, etc. The only contact insecticide which should be added to grain is malathion and then only if the store has a previous history of infestation.

(iii) *Infestation in retail shops and domestic larders*

To a large extent, the manufacturers or wholesale merchants will have eliminated insect infestation from foodstuffs before they reach the shop or home. But, inevitably, there are occasionally a few insects which slip through into bags or packets of the finished product. Perhaps the most common offender among the beetles is *Stegobium paniceum*. Less frequently, *Tribolium* sp. is found in bagged flour. Among the moths, *Ephestia elutella* turns up from time to time in chocolate, while *Plodia interpunctella* or less often *Cadra cautella*, are found in dried fruit. When there is rapid sale and consumption of the product, these insects may escape notice, unless they are well grown. It cannot be said that these insects are actually harmful, if eaten, other than psychologically. But if they are detected, complaints and legal action may follow. In general, it will be admitted that insect infestations tend to indicate poor hygienic standards.

If infested food is kept for long in storage, the pests will multiply and probably spread, eventually, throughout the store. Contamination of clean packages can be prevented by adequate wrapping; but this is more difficult to achieve than might appear. Cardboard and metal foil wrapping is not usually effective, because crevices are left through which tiny insects can penetrate. Sealed wrappings of wax paper or plastic are adequate for mechanical exclusion of feeble pests. But some insects are easily able to bore through paper, card or thin plastic. For protection against such intrusive forms, insecticidal treatment (based on pyrethrins) may be desirable.

In order to prevent insect damage in food stores, it is important, therefore, to be alert for the first signs of a pest. Adults or larvae may be seen wandering about on shelves or on adjacent walls or windows. Even suspicious-looking holes in packets or bags should give the warning.

The first essential is to trace all the breeding sites and to segregate the infested products. When a store has been badly neglected and there is a very widespread and

general infestation, it may perhaps be necessary to resort to fumigation. Normally, however, it should be sufficient to remove and destroy very badly infested materials. Less badly infested products can be salvaged, either for human or animal consumption. Dry foods (cereals, beverage concentrates and spices) can be simply disinfested by heat treatment (see p. 83). This is not always feasible with moist sugary or fatty foods (dried fruit or dried meats) but if they are only lightly infested they may be cleaned by discriminative elimination.

The possibility of allowing a permanent infestation to develop, in spillage and debris, exists even in small stores and larders. Such pests as *Stegobium* thrive in almost any dry organic matter. Therefore, the eradication of an infestation should conclude with a thorough cleansing of the whole store and the application of an inoffensive insecticidal spray. Finally, good ventilation is most important, for many pests can only thrive under damp conditions.

### III · BLOWFLIES etc.

A few kinds of fly are liable to breed in various foodstuffs; but these have been dealt with in Chapter 8 as 'houseflies and blowflies'. They include:

- (a) Blowflies, which breed in raw or uncooked meat or fish, e.g. *Calliphora*, *Lucilia*, *Sarcophaga* and *Phormia* (pp. 174-178).
- (b) Fruit flies, which breed in over-ripe fruit, decaying vegetables and milk curds, e.g. *Drosophila* (p. 180).
- (c) The cheese skipper *Piophilidae casei*, which occurs in cheese and smoked meats (p. 181).

### IV · BOOKLICE (Psocoptera)

These small, flattened, yellowish, frequently wingless insects may occur in various places in dwelling houses. They feed on minute moulds and fungi and are therefore only liable to thrive under slightly damp conditions. They are dealt with more fully as 'nuisances' in Chapter 16; but occasionally they may be found infesting various kinds of foodstuff, especially packaged cereals, sugar, etc. It is quite possible that this may often be accidental contamination due to the foodstuff being kept in a rather damp store infested with psocids. Lightly infested foods can easily be disinfested by heat treatment (p. 83).

### V · MITES (Acarina)

Various mites may occur in stored foodstuffs, particularly under conditions of high humidity. Most abundant are the herbivorous mites, which feed on the food, belonging to the family Acaridae. In addition, there may be predaceous mites present, which are beneficial inasmuch as they destroy the harmful species. These predaceous mites occur in diverse branches of the Acarina.

STORED FOOD MITES (Acaridae)<sup>(23)</sup>(a) **Distinctive characters**

The mites concerned are about 0.5 mm long; that is, about the size of the eggs of many stored food insects. To the naked eye, they appear as small white dots, which move slowly away from a source of illumination. When very numerous, these mites form a characteristic buff-coloured dust, made up of the mites themselves and their cast skins. Also there is a peculiar 'minty' smell, easily recognized, if one crushes some of the mites. Under the microscope, the mites are pearly white, often with tan-coloured legs, and usually with numerous outstanding long bristles. Their general appearance can be seen from the examples in Fig. 38.

The acarid mites of stored food belong to two sub-families distinguished as follows:

Anterior part of the body separated by a transverse suture	Tyroglyphinae
(e.g. genera: <i>Acarus</i> , <i>Tyrophagus</i> , <i>Caloglyphus</i> , <i>Rhizoglyphus</i> , <i>Suidasia</i> , <i>Thyreophagus</i> )	
No transverse suture separating anterior part of body	Glycyphaginae
(e.g. genera: <i>Glycyphagus</i> , <i>Carpoglyphus</i> , <i>Gohieria</i> )	

(b) **Occurrence and biology of various mite pests**The flour mite (*Acarus siro*)<sup>(27, 54)</sup> (Fig. 38a)

This is the commonest of the mite pests of stored food.

*Appearance.* The body is colourless, the appendages varying from pale yellow to reddish brown; the hind end being smoothly rounded in the male (0.32–0.42 mm) and slightly indented in the female (0.35–0.65 mm). Two pairs of bristles trail from the hind end of the body.

*Occurrence.* In addition to flour, *A. siro* occurs on all kinds of farinaceous products, on cheese, grain, hay, etc.

*Life history.* Under optimum conditions, the females can lay up to 500 eggs, during a lifetime of about 40 days. The eggs, laid loosely in the food, measure about 0.15 × 0.08 mm. The larvae which hatch from the eggs are about 0.15 mm long and have three pairs of legs. After feeding for some days, the larva becomes inert and then moults to produce the first nymphal stage, which, like all later stages, has four pairs of legs. Subsequently, the nymph moults to produce a second nymphal stage, which finally moults again to produce the adult. In some mites a relatively (or completely) inactive stage called a 'hypopus' is produced, instead of the second nymph; this is resistant to low humidity and other adverse conditions. Formerly it was thought that hypopi commonly occurred in strains of *A. siro*; but it is now recognized that they are seldom formed in this species, most of the earlier reports relating to a closely related species (*A. farris* Oud.) which does not generally occur in stored food.

*Speed of development.* At 18–22°C (64–68°F): E, 3–4; L, 4–5; NI, 6–8; total about 17. At 10–15°C (50–59°F): total about 28. At 5°C (40°F): total about 140.

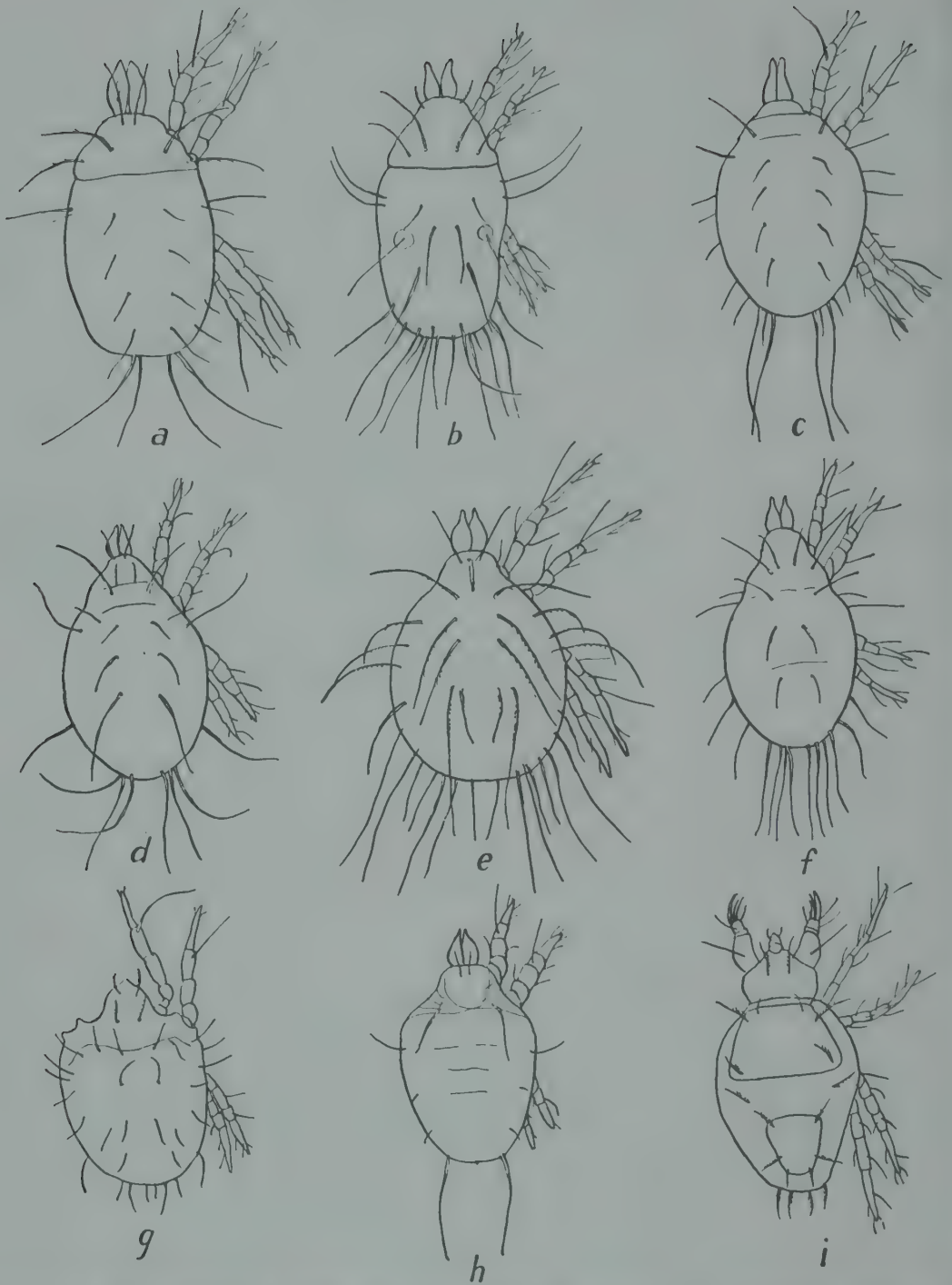


FIG. 38. Mites occurring in stored food. (a) *Acarus siro* (male); (b) *Tyrophagus casei* (male); (c) *Carpoglyphus lactis* (female); (d) *Caloglyphus berlesei* (male); (e) *Glyciphagus domesticus* (female); (f) *Rhizoglyphus callae* (male) (rather similar to *R. echinopus*); (g) *Gohieria fusca* (female); (h) *Suidasia nesbitti* (male); (i) *Cheyletus eruditus* (female). Magnifications: (f)  $\times 40$ ; (a) (d) (e) (g)  $\times 55$ ; (b)  $\times 80$ ; (c) (h) (i)  $\times 90$ . After Hughes, A. M., *The mites of stored food*, H.M.S.O. (1961).

*Ecology.* Flour mites require a moderately high humidity in order to proliferate. They will not thrive on grain or flour with a water content below 13% (in equilibrium with air at 65% R.H.). A slight rise above this level (say, to 14% water content; 70% R.H.) will allow ready breeding. At 15 to 18% water content (75–85% R.H.), infestations increase to serious proportions. The mites can distinguish air at favourable humidity and choose regions with 75 to 85% R.H. if offered a choice (higher, as well as lower, humidities being avoided). Quite often, an infestation is confined to the superficial layer of flour or grain, which has, in some way, become damp.

The optimum temperature range for the mite is rather low (about 18–25°C). This is affected by the humidity, the maximum proliferation rate at 80% R.H. being 25°C, while at 90% R.H. it is 22°C. As well as the optimum, the overall temperature range of flour mites is also rather low, as compared to most stored food insects. Thus the upper limit, at which they can breed and survive, is just over 30°C (86°F); whereas they can increase (slowly) at low temperatures, such as 5°C (41°F) and persist for a long time at temperatures around freezing.

The flour mite is often preyed upon by *Cheyletus eruditus* (Fig. 38i, see p. 333). Environmental conditions act differently upon the two mites, *Cheyletus* being more dependent on warmth and *Acarus* on moisture. In mixed populations, therefore, *Acarus* is more abundant in winter and *Cheyletus* gains the upper hand in summer.

Mites are sometimes accused of spreading moulds and fungi in cereals. However, it seems more likely that they appear together because the same moist conditions favour both of them. In fact, there is evidence that the mites feed on the fungi and reduce their prevalence.

#### The cheese mite (*Tyrophagus casei*) (Fig. 38b)

*Appearance.* Mites of the genus *Tyrophagus* have at least 4 pairs of long bristles trailing from the hind end of the body. *T. casei* is one of the larger, more clumsy species, with well-tanned legs. Males measure 0.45–0.55 mm; females 0.50–0.70 mm. Other species of *Tyrophagus* not uncommon are *T. putrescentiae* and *T. longior*. The former prefers foods with high fat or protein content (linseed, dried egg, cheese); the latter occurs on cheese but also on home-produced grain, straw and hay.

*Occurrence.* As well as on cheese, *T. casei* is found on various other stored foods, on grain, damp flour, old honeycombs, etc. *T. casei* has been maintained in culture for addition to the particular brand of cheese known as Altenburger, to which it is supposed to impart a piquant taste. When 'ripe', the surface of the cheese is covered with a greyish powder consisting of enormous numbers of the mites (living and dead) together with their cast skins and faeces. Other cheeses may sometimes become infested with *T. casei* or other mites, but in Britain this is generally regarded as distasteful. The mites eat out small holes and cause accumulations of brownish dust.

*Biology.* The life history resembles that of *A. siro* in many respects. The life cycle takes 15 to 18 days at 23°C (73°F) and 87% R.H.

#### The dried fruit mite (*Carpoglyphus lactis*)<sup>(53)</sup> (Fig. 38c)

*Appearance.* As in *A. siro* there are 2 pairs of bristles trailing from the hind end of the body; but there is no suture dividing the body into two. The appendages are slightly pinkish. Males, 0.38–0.40 mm; females, 0.38–0.42 mm.

*Occurrence.* This mite is commonly associated with dried fruits and jam, though it is by no means the only species found in such products. (Another mite favouring this type of food is *Thyreophagus entomophagus*, which may also occur in flour stored for long periods.)

*Biology.* The females have been recorded as laying from 25 to 72 eggs in a week. The mites themselves can survive for 40 to 50 days.

#### *Other mites infesting stored food*<sup>(53)</sup>

*Glyciphagus destructor*, resembling the house mite *G. domesticus* (Fig. 38e) (see p. 417), is common on many kinds of stored food, often in company with *Acarus siro* and the predator *Cheyletus eruditus*.

A mite with notably different appearance from other tyroglyphid pests is *Gohieria fusca* (Fig. 38g). The body is covered with a pinkish-brown cuticle, giving it a superficial resemblance to the beetle mites. It occurs in flour, rice, corn, bran, etc.

Certain mites seem to require exceptionally moist medium to thrive and are found in particularly damp grain, nuts, bulbs, etc. Examples: *Rhizoglyphus echinopus* (Fig. 38f) and *Caloglyphus berlesei* (Fig. 38d).

### (c) Importance of mites in foodstuffs

#### (i) Harm to foodstuffs

Several of the species of mites referred to above may cause deterioration in stored food, but the most common source of trouble is *Acarus siro*. This cosmopolitan mite is troublesome not only in grain stores, mills and bakeries, but also in larders of private dwellings. It is primarily a pest of cereals and cereal products. In stored grain it tunnels into the germ and consumes the best parts of the seed; and in flour too it probably attacks the more valuable food constituents, selectively. In addition to reducing the food value, a heavy mite infestation causes tainting. Bad taint occurs if there are over 500 mites per 100 grams food. The cereal acquires a characteristic musty or sour smell which is usually described as 'minty'. (This is due to secretion of the mites, apparently arising from two dorsal glands.) The taint may be largely removed from grain in the cleaning and washing processes before milling but in grain products, such as flour, it is a serious problem. Mitey flour used in mixtures such as pudding powder, custard powder, etc., usually results in unpalatable cooked articles. If it is used for bread making, the bread has a sour taste, poor odour and may not rise adequately.

#### (ii) Dermatitis

Various acarid (and other) mites have caused dermatitis in people handling infested products. Probably almost any species could cause skin reactions in sensitive people coming into contact with large numbers. The following have actually been recorded as causing this trouble: *Tyrophagus casei*, *T. longior*, *T. putrescentiae*, *Caloglyphus krameri*, *Suidasia nesbitti*, *Glyciphagus domesticus* and *Carpoglyphus lactis* (see p. 275).

(d) **Control of mites in foodstuffs**<sup>(34)</sup>

The simplest method of mite prevention is to keep cereal products sufficiently dry, so that their water content remains below 12 to 13%. Stores and larders should be reasonably well ventilated and care taken that food in bags is not allowed to come in contact with condensed moisture or stone or concrete walls or floors.

Packages of foodstuffs which are free of mites can be protected from them by efficient sealing, with wax-paper, foil or plastic sheeting. The sealing must be complete, however, because packaging which allows the mites entry may actually encourage them by retaining moisture. Cheeses may be protected by careful dipping in wax to provide a complete coating.

Mite infestations may be simply destroyed by heating (p. 83). They are also killed by the various fumigants which may be used for stored product pests generally; but these are seldom to be employed in small infestations.

## VI · BENEFICIAL INSECTS AND MITES

The following organisms, which may be found in or near stored food products, may be described as beneficial since they destroy a certain proportion of pests, which they attack as parasites or predators. Generally, however, they are not very important since they are only able to flourish when the pest species is thriving.

(a) **Insects**(i) *Hemiptera*

Two species of bug may be encountered in food stores, especially large ones such as warehouses and granaries. In their young stages, they resemble the nymphs of bed bugs and they therefore sometimes give occasions for surprise and concern. However, they are quite harmless to man and even beneficial, since they live by sucking the juices of the beetles and moths or sometimes of mites. These two species may be distinguished as follows:

Second segment of the antennae considerably longer than the third. About 3·5–4 mm long in the adult. Back of thorax dark brown to nearly black. Forewings and legs yellowish brown. *Lyctocoris campestris*

Second segment of the antenna about the same length as the third. Adult about 2 mm long, more reddish than the above and with the wings stunted. *Xylocoris flavipes*

(ii) *Diptera*

*Scenopinus fenestralis* (the 'window fly')

The larvae of this small fly prey upon the larvae of various other insects. For example, it may occasionally be found among grain, destroying moth caterpillars and beetle grubs: and it has also been said to attack larvae of carpet beetles and clothes moths (see p. 357 and Fig. 41).

The larva of *Scenopinus fenestralis* is fairly easily recognized. It has a long, narrow, segmented body, yellowish white in colour, with a distinct head and a few, rather

prominent bristles. The abdominal segments are sub-divided, so that the insect appears to have 17 abdominal and 3 thoracic segments. The adult fly is a small, rather hump-backed fly, with greyish-yellow bristles on the thorax and a dark flattened abdomen.

(iii) *Hymenoptera*

*Ichneumonidae* (Ichneumon flies)

*Braconidae* (Braconid wasps)

A large number of rather specialized members of the order Hymenoptera have larvae which develop parasitically inside other insects. Those species which attack pests of stored products are small or minute black insects which look rather like tiny flies but are easily distinguished by possessing two pairs of wings. The wings, especially

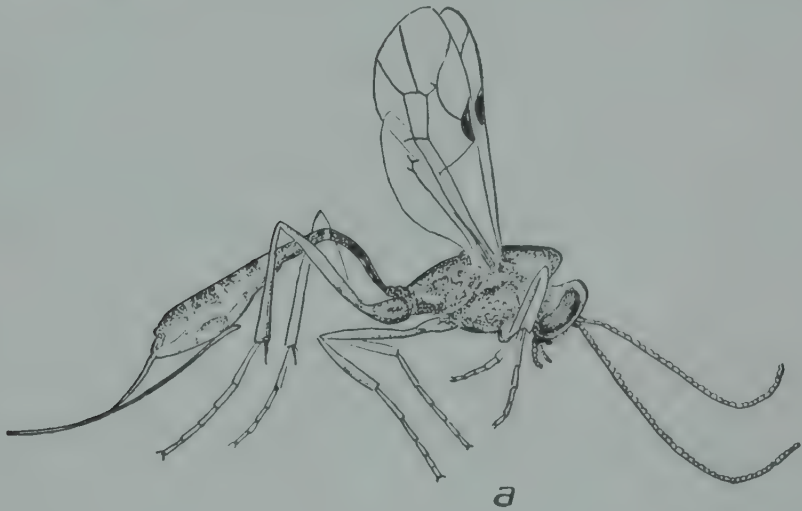


FIG. 39. *Parasitic Hymenoptera*. (a) *Nemeritis canescens* (Ichneumonidae); (b) *Microbrachymeria hebetor* (Braconidae). (a) after Freeman and Turtle (*Insect pests of food*, H.M.S.O., 1947) (b) after Richards and Herford, *Ann. appl. Biol.* **17** (1930). (a)  $\times 7\frac{1}{2}$ ; (b)  $\times 15$ .

the hind pair, are rather sparsely veined and there is often a dark spot about the middle of the anterior edge of the front pair. The Ichneumonidae are characterized by very narrow, extended 'wasp-waists'.

Although these parasitic insects are beneficial in so far as they attack pest insects, they do not occur in large numbers unless the host population is already very high. Therefore, their presence should be taken as an indication that control measures against the pest are long overdue.

Some typical parasitic Hymenoptera are shown in Fig. 39. The life histories of these parasites are similar in general form. The adult female injects an egg into the body of the host caterpillar or grub with her long ovipositor. The egg hatches inside and the parasite larva develops as a white, legless maggot. This grows gradually as it consumes the body of the host which eventually dies. The parasite then emerges and spins a small, yellowish, oval cocoon and pupates inside. Eventually the adult emerges, the sexes pair and the females seek fresh prey for their offspring.

### (b) Mites

#### (i) *Pyemotidae*

*Pyemotes ventricosus* (the grain itch mite) (Fig. 31)

This mite is curious in several respects. It is beneficial in that it is parasitic on a variety of pest insects in their larval stage. (Biologists have suffered when laboratory cultures of certain pests have been destroyed by the mite!) But the mite itself can be a nuisance to people handling infested foodstuff for long periods, since it causes an irritating, though transitory, dermatitis (see p. 274).

The life history is unusual. The young fertilized females, which are normal-looking mites, seek out suitable hosts, insert their mouth-parts and become permanently attached. The hind part of the body becomes gradually swollen into a relatively large white globe about 1 mm in diameter. The eggs hatch and the entire development of the young takes place inside the body of the mother. After about 10 or 11 days (at 25°C; 77°F) the progeny begin to emerge and they may continue to be produced over a period of 9 to 33 days. As many as 36 births have been observed in a single day, the largest total number being 242.

Only about 3-4% of the offspring of fertilized females are males. These remain for 20 to 30 days on the body of the mother, apparently living parasitically on her, for if they are removed they die in 20 hours. The males remain close to the genital aperture of the mother and assist in the emergence of their sisters with whom they immediately mate. Each male mates with about 30 females altogether. The fertilized females scatter to seek new hosts to parasitize and the cycle begins again. If they are unsuccessful, they die after about 48 hours.

Females which are not fertilized sometimes produce young parthenogenetically, in which case the progeny are all males.

#### (ii) *Cheyletidae*

*Cheyletus eruditus* (Fig. 38i)

This mite occurs fairly commonly among grain and grain products where it lives by feeding on other mites, chiefly *Acarus siro*. Under conditions which are unfavourable to the latter, the predator may completely suppress it.

The life history is normal except that reproduction is parthenogenetic; there are one larval and two nymphal stages before the adult. The younger stages may feed on the eggs rather than the active stages of other mites. The mites seize their prey with their powerful palps, insert their beak-like mouthparts and suck it dry. The whole process takes about a quarter of an hour.

There is an interesting ecological balance between *Cheyletus*, its chief victim *Acarus siro* and the environment. *Acarus* is very dependent on water content of the food, and its numbers rise enormously as this increases. *Cheyletus* populations increase too with the rise in numbers of their prey, but less rapidly. On the other hand *Cheyletus* can occur at lower water contents than *Acarus* and under these conditions it may completely suppress the grain mite. When the latter is absent, *Cheyletus* feeds on other mites or, for a short time, may continue existence by cannibalism.

As already mentioned, *Cheyletus* tends to be dominant in the summer and *Acarus* in the moister, cooler conditions of winter.

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## 12· *Insect pests in waste products*

The waste products of a modern community are eliminated in two ways: as relatively dry refuse or as water-borne sewage. In the course of disposal of these substances there often arise outbreaks of insects which may develop into vexatious nuisances. These troubles will be considered in this chapter.

### *A·Refuse*<sup>(1, 2, 10)</sup>

#### I·NORMAL DOMESTIC REFUSE

##### (a) **Nature and amount**

The average composition of domestic refuse from urban districts in Britain has been analysed in various ways at different times. The following are typical figures obtained in summer months, in recent years.<sup>(9)</sup> *Non-combustible matter*: Fine dust 16–20%; Metal, 7%; Glass, 6–9%. *Combustible matter*: Small cinders, 9–10%; Large cinders, 6–9%; Paper, 18–21%; Rags, 1–2%. *Vegetable and other putrescible matter*: 25–26%. *Miscellaneous*: 2–4%. A comparison of these data with earlier assays suggest that the proportion of fine dust has declined (possibly owing to the decline in coal fires) while proportions of metal and glass have risen.

The overall figures give an average of about 1·7 lb per person per day; but the figures for winter months may be about 25% above and in the summer 25% below the mean. The composition as well as the total amount varies in different seasons, for the simple reason that in winter there are more domestic fires burning, with consequent increases in ashes and cinders. In summer, on the other hand, there are rather more fruits and vegetables available. Thus, in December to February cinders may constitute 32% and putrescible matter only 9% of the total; whereas in June–August the cinders may amount to only 15% and the putrescible matter rises to 24%.

##### (b) **Collection of refuse in dustbins**

Garbage contains a considerable proportion of decomposing organic matter which is attractive to flies and can provide them with suitable breeding material. Recent surveys show that blowflies (*Calliphora*, *Lucilia*, etc.) are more prone to infestation of domestic refuse in dustbins than ordinary houseflies. In any case, it is very desirable to prevent the accumulation of flies in the dustbin area and to prevent them gaining access to the refuse. Both can be achieved by proper hygienic practices.

The dustbin area should be clean and tidy. Where a number of dustbins are collected (e.g. behind restaurants or hotels) it is very desirable that they should stand on a smooth concrete surface, sloping to a drain, so that the area can be hosed

down regularly. The dustbins themselves should be in good condition with well-fitting lids, which are kept in place. Too often one sees a collection of battered bins and sometimes odd drums and wooden boxes used to store refuse. Old bins sometimes accumulate a layer of filth in the bottom which clings to the bin when the refuse is collected. This can be avoided by wrapping wet refuse in paper, or at least lining the bottom of the bin with paper.

To supplement the hygienic measures, especially where many bins or especially attractive refuse is present (e.g. from fishmongers, butchers, etc.) the outsides of the bins and the adjoining walls should be sprayed weekly with a 5% suspension of DDT.

Collection of refuse by the local authority should be made at least weekly and preferably twice weekly in the summer.

One of the most promising new developments, which unfortunately has not yet been widely adopted, is the use of paper sacks to replace dustbins. Their somewhat greater cost is offset by reduction in labour of collection and they present less opportunity for insect breeding, since they are renewed at each collection.

### (c) Disposal of refuse

The method of disposal of domestic refuse can be chosen by the local authorities responsible for its collection, in accordance with the facilities available and its own financial policy. Some boroughs endeavour to recover part or all of the costs of refuse elimination by various utilization schemes. These processes usually begin with rough sorting in which bottles and large metal objects are removed. The residue can either be (i) burnt, preferably in a plant which can utilize the energy evolved by the combustible matter present or (ii) crushed and converted into fertilizer. (The value of the refuse itself, in this respect, is poor; but it may be improved by addition of sewage sludge and composted, either in brick cells or in the open. These processes, fortunately, do not give rise to insect nuisances.)

Utilization schemes, however, are not very common, either because the financial benefit is considered uncertain or because the smaller boroughs do not have the special plant necessary. Therefore a very common method of refuse disposal is by simple dumping. Apart from disposal at sea, this involves forming a large accumulation of refuse in some isolated waste ground. (Choice of a suitable site is difficult in many areas.) Wherever possible, it is desirable to utilize the refuse for land reclamation. Marshy lands, sandy wastes, ravines, disused quarries and pits may be eventually improved by dumping. Furthermore, in most of these cases, the refuse will be used for filling in cavities and depressions instead of forming unsightly mounds. (Two large dumps at South Hornchurch, formed of refuse from the city of London, were estimated in 1928 to be  $\frac{3}{4}$  mile long, nearly  $\frac{1}{3}$  mile wide and up to 90 feet high.) Pits and depressions containing standing water, however, cannot always be used; and in any case they require special consideration, because of the probable pollution of the water by percolate from the refuse.<sup>(9)</sup>

Refuse dumps can be highly unpleasant, both in themselves and in their effects on their surroundings. The organic materials present may provide food for multitudes of insects and for rats; fires may start and spread smoke and an unpleasant

effluvia; light rubbish (paper and rags) tends to get blown about. Most of these defects are due to a large exposure of recently tipped refuse, and they can be substantially reduced by proper systematic tipping.

#### (d) 'Controlled tipping'<sup>(5)</sup>

The principle of this method is to keep the tipping face small, so that fresh refuse is rapidly covered up by further loads. The dump is therefore formed in long tongues, which fill up the site in strips. These tongues should be about 6 feet deep and of a width depending on the number of vehicles constantly discharging. When the floor of a large depression (e.g. an old quarry) has been filled in, a further layer may be commenced, provided that sufficient time has been allowed for subsidence of the first layer of strips. As the face of the tip advances, the top and the exposed side (or sides) should be covered with earth, flue dust or fine ashes, if possible, to a depth of 9 inches. For large tips, the use of bulldozers or earth-lifting machines will be found exceedingly helpful.<sup>(2)</sup> The track taken by the tipping vehicles must, of course, move forward with the tipping face. Often it is necessary to lay sleepers on the top of soft rubbish, to carry the vehicles. The frequent passage of loaded vehicles over the dump has a beneficial effect in consolidating the tipped refuse. Where possible, it is desirable to flatten tins and drums and to fill tin baths, etc. with small refuse. Otherwise these hollow articles will collapse after some months and cause unequal subsidence in the completed dump. There will, in any case, be some general subsidence owing to the decomposition of organic matter in the refuse.

Under the conditions described, the heat generated by decomposition of organic materials is retained and the whole mass of refuse becomes hot for several weeks after tipping. The degree and persistence of heating depends partly on the nature of the refuse and partly on the way it is tipped. Where the rubbish is spread out (indiscriminate tipping) heat is soon lost; when controlled tipping is practised, the large volume of the refuse with the outside covered or, at least, well compacted correspondingly retains its heat.

#### (e) Refuse tips and insect infestation

The most troublesome insects associated with refuse tips are blowflies, the housefly and the cricket. (Their general biology, habits and control are dealt with elsewhere, see pp. 174, 153 and 420.) Dumps which are badly infested with these pests may be responsible for nuisances in houses up to about half a mile away. Liability to insect infestation is greatly reduced by the practice of controlled tipping for the following reasons:

(i) The use of earth or other material to cover the refuse and the reduction of the surface area of attractive fresh refuse, prevents extensive oviposition of flies after tipping and therefore reduces additional breeding in it. For this reason, the cover must be applied as soon as possible and certainly within 24 hours of tipping. The cover also prevents access of crickets to the food and, where they are present, will imprison and destroy many of them.

To be effective, the covering material must be finely grained; coarse cinders and clinker are useless.

(ii) The retention of refuse in a large mass and the compaction of the outside, conserves the heat of fermentation so that the bulk of the dump is too hot for insect breeding. Some of those present may actually be destroyed by the high temperature.

(iii) A cover of earth prevents the emergence of a proportion of fly adults, even if the maggots were present before tipping; but to retain a high percentage, a layer at least 9 inches deep is required. This is seldom practicable.

Where an insect nuisance develops in spite of controlled tipping, recourse must be made to insecticides. A simple and fairly effective measure (against both flies and crickets) is to apply 0.5 to 1% *gamma* benzene hexachloride dust at the rate of 1 cwt per acre with a rotary blower. The treatment may have to be repeated several times at weekly or fortnightly intervals to cure bad infestations.

## II. REFUSE FROM SLAUGHTER HOUSES<sup>(3)</sup>

There are some 500 licensed slaughter houses in England and Wales, ranging from very large municipal types to small affairs, little more than an outhouse to a butcher's shop. Almost all suffer from blowfly infestation to a greater or lesser degree. The flies concerned are *Calliphora* (mainly *C. erythrocephala* with some *C. vomitoria*), *Lucilia* (about 95% *L. sericata*, with some *L. caesar*, etc.) and *Phormia terrae-novae*. Their biology is described in Chapter 8 (pp. 174-178).

In basic design, the slaughter house comprises (1) the *lairage*, where animals awaiting slaughter are kept, (2) the *slaughter room*, where the killing and separation of edible and inedible materials occurs and (3) the *hanging room*, where meat and offal are hung to cool and inspection and grading takes place.

### Nature of the refuse

The refuse from slaughter houses comprises the following:

#### 1) *Condemned meat and offal*

This is usually stored in an outbuilding but often heaped in an open yard. The period of storage ranges from a day at most large slaughter houses to 3-4 days at small rural establishments.

#### 2) *Inedible gut*

This is usually kept in open metal drums and the period of storage varies as much as for the condemned meat and offal.

#### 3) *Blood*

As much blood as can be saved is stored in tanks or metal drums awaiting collection.

#### 4) *Refuse*

This consists of dung from the gut of slaughtered beasts, sweepings from the yards and floor of the slaughtering bays, waste pig hair, wool and hide and sometimes

congealed blood from traps in the drainage system. This mixture is usually tipped into a pit or heaped in an open yard where it may remain any period from 2 hours to 8 days. It forms an ideal breeding material for blowflies and because of the heat of putrefaction, promotes their rapid development.

### Hygienic control measures

A great deal can be achieved in preventing blowfly nuisance by a high standard of cleanliness. This is much easier to achieve at modern, well-designed slaughterhouses than at old-fashioned inefficient premises, where the staff tend to become frustrated and eventually resigned to hordes of blowflies. The following measures are recommended.

#### (1) *The midden*

Blowfly eggs can develop to migrating larvae within 3 days so that refuse should be removed within this period, and preferably daily. To facilitate this, in a large establishment, rotational storage and collection should be employed. The midden yard is divided by brick walls into bays, which are filled and emptied in turn, so that no refuse remains in place more than 2 days. As each bay is emptied, it is thoroughly cleared and hosed down.

This arrangement will prevent a local breeding nucleus in the dangerous neighbourhood of the slaughter house. Furthermore, many of the larvae in the refuse will be killed by heat due to storage in depth during and after transportation to the disposal site.

#### (2) *Blood, inedible meat and offal*

These should be stored in outbuildings. The blood and offal should be kept in heavy, galvanized-iron bins with strong lids, not in the open oil-drums often used. All bins should be emptied every second day at the maximum and hosed out before re-use.

#### (3) *Destructible waste*

Destructible waste should be burnt, daily if possible. This includes discarded aprons and other clothing, sacking and rags used for swabbing, blood-soaked sawdust, etc.

### Chemical control measures

The hygienic measures described are aimed mainly at larvae; chemical control is directed against adults, to prevent them ovipositing. Experiments have shown that the simplest and most effective insecticides are dusts containing 5% DDT or 0.5% gamma BHC. The dust should be liberally applied daily to the surface of all exposed refuse, to adjacent walls and vegetation. A convenient time for dusting is late afternoon, when all refuse has been deposited for the day. Every 6 weeks, a dusting of vegetation and walls within about 50 yards of the midden is also advisable. This practice has been found to give good control, when combined with hygiene, and resistance was developed in 3-4 years of regular use.

## *B. Sewage*

### I. COLLECTION AND TREATMENT OF SEWAGE

In nearly all towns and cities in Britain, water-borne waste is collected by a sewage system. This removes water closet excreta and dirty water from dwelling houses and rainwater from gutters and road drains. (The rainwater is often conducted along separate sewers.) In addition, some manufacturing effluents can be discharged into the drains. Sewage is collected in a network of conduits, so constructed that there is normally a gentle flow which changes to a rapid, self-scouring stream at the daily periods of peak load. In this way, the effluent is carried to the disposal works.

Sewage purification consists, essentially, in the removal of the grosser solids, the coagulation and precipitation of finer suspended solids and the oxidation of most of the remaining impurities. These objects are attained in stages, as follows:

- (i) Coarse screening (to remove debris).
- (ii) Partial sedimentation (to remove grit and sand).
- (iii) Further sedimentation in temporary storage tanks (to allow settlement of 'sludge').
- (iv) Oxidation (i.e. largely, aerobic bacterial decomposition) by (a) irrigation of land (a slow and rather obsolete process), or (b) aeration, by bubbling air through 'activated sludge' tanks, or (c) sprinkling the effluent over percolating filters (see below).
- (v) Final sedimentation.
- (vi) Discharge into a river.

### II. THE FAUNA OF PERCOLATING FILTERS<sup>(11)</sup>

Only one of the above processes is important in regard to insect nuisances; that is the percolating filter. This type of filter is efficient and simple and it is very widely used. It consists of a bed of a coarse filtering medium (pebbles or clinker) either circular or rectangular in form and 3 to 10 feet deep. The sewage is sprinkled over this from either stationary or, better, from travelling jets. Over the pieces of broken solids, which constitute the filter, there grows a thick film of fungi and other organisms. In the upper layers, there is a leathery growth of the fungus *Phormidium* with a slight admixture of *Ulothrix* and other algae. In the depths, there is a slimy zoogloea of bacteria, fungi, protozoa and other organisms. This 'biological film' is important in the purification of the effluent trickling over it. Living in the film, and feeding on it, are a number of small animals, chiefly insect larvae and worms. The number of types present is not very large and a few species predominate. The characteristic fauna includes the following groups:<sup>(8)</sup> (1) Oligochaete worms, especially *Lumbricillus lineatus*. (2) Springtails (Collembola) especially *Hypogastrura viatica* and *Tomocerus minor*. (3) Small flies, belonging to the families Psychodidae, Chironomidae and Anisopodidae. (4) Spiders of the family Linyphiidae.

Some of these organisms are beneficial, in that they prevent the fungal mat from

growing so dense as to clog the filter. This may happen in the winter, when the rate of reproduction of insects is low, so that there is a danger of 'ponding'. In the spring, the activity of the scouring organisms accelerates and much of the old film is destroyed and broken away; this is known as 'off-loading'. Subsequently, however, a new and more vigorous film regenerates.

During the summer, in certain seasons, there may be enormous proliferation of some of the flies, resulting in swarms which constitute a nuisance.

### III. TROUBLESOME FLIES BREEDING IN PERCOLATING FILTERS

#### (a) Species concerned

The flies most frequently reported as causing nuisance in the vicinity of sewage works are the following:

- (i) the psychodids, especially *Psychoda alternate* and *P. severini*;
- (ii) *Anisopus fenestralis*;
- (iii) various chironomids, such as *Spaniotoma*, *Metriocnemus* and *Chironomus*.

(The adults can be distinguished with the help of the key on page 441 and Figs. 15*a* and *b*; the larvae are shown in Figs. 16*a* and *b*.)

Most irritating are the minute psychodids which get into the eyes, mouth and nostrils of workmen in the sewage works and people in the vicinity. All the species tend to enter houses (see p. 172). The chironomids may breed in large numbers in places other than sewage works (see p. 205).

#### (b) Biological data<sup>(6, 7, 14)</sup>

##### (i) *Psychoda* spp. Moth flies

##### *Life history*

The eggs are laid singly or in groups on the biological film at various depths in the filter bed. These minute white, oval eggs are about 0.2 mm long. The larvae which hatch from them are slow-moving, legless grubs, with a distinct head bearing powerful mandibles. These grubs feed on the algae, fungi, bacteria and sludge which made up the film and break it down into small faecal pellets which are easily washed away. They breathe atmospheric oxygen through two spiracles on a 'siphon' at the end of the body; usually this siphon is the only part of the body to project from the biological film in which the larva lives.

The larva grows gradually from about 1 mm to 9 mm in length, moulting three times in the process. Then it turns into a pupa, with two respiratory horns at the anterior end. Finally the pupal skin splits and the adult fly emerges. The flies cluster together on the drier parts of the filter, on the filter wall, etc. Here mating takes place, except in one species (*P. severini*) in which males have never been discovered in Britain, and in which the females lay fertile eggs without mating. The females lay up to about 100 eggs each.

*Speed of development*

The incubation of the eggs takes 1 to 6 days and larval life 10 to 50 days according to the temperature. There are apparently about eight generations in the course of the year. There are usually several peaks of abundance of the adults corresponding to the emergence of various generations.

(ii) *Anisopus fenestralis*.<sup>(4)</sup> The window gnat*Life history*

The female lays its eggs in a mucous ribbon which is traversed by a network of refringent strands. This ribbon forms a grey spherical mass, containing upwards of 150 eggs; and these masses may be found on the film or the wet filtering medium. After a few days the gelatinous material breaks down and the young larvae emerge. Like the larvae of *Psychoda*, they are legless grubs, but they are brownish in colour and considerably more active. They, too, feed on the biological film and remain partly immersed in it, with the posterior siphon projecting. The larvae grow to a length of about 20 mm and then pupate. The pupa is capable of limited movement which enables it to move to a relatively dry place suitable for emergence of the adult fly. The adults are relatively inactive and are often seen at rest upon the walls of the filter in which they breed; they may, however, be wind-borne for distances up to a mile from the filters.

*Speed of development*

At 20°C (68°F) the life cycle is completed in 35 days (4 days in the egg; 20 days in the larval stage; 8 days as a pupa and 3 days pre-oviposition period). At 10.5°C (51°F) the complete cycle takes 88 days, of which 50 are spent as larvae. At summer temperatures, the life of the adult fly is about 7 days.

(iii) *Chironomids*. Midges

Flies of the genera *Metriocnemus* and *Spaniotoma* breed in the biological film of the filters. *Spaniotoma minima* and the less common *S. perennis* are distributed throughout the filter bed; but *Metriocnemus longitarsus* and *M. hirticollis* larvae tend to climb up into the upper layers. *Metriocnemus* spp. are strongly predaceous, feeding on eggs and pupae of other species and, perhaps, their own. The eggs are laid in gelatinous masses and hatch to give active creamy-white worm-like larvae. These feed not only on the film but also on eggs, larvae and pupae of their own and other species. Both genera form cocoon-like cases in which to pupate. The adults emerge and form 'dancing' swarms in the air before mating. *Metriocnemus longitarsus*, however, can mate in confined spaces, unlike the other species.

The larvae of *Chironomus* spp. do not occur in the actual filters but often breed in drains and effluent channels. They contain haemoglobin dissolved in the blood and are commonly known as 'blood worms' from their red colour. The larvae make tubular shelters which adhere to the humus, sludge, etc., on which they feed. The adult fly emerges from the pupa at the surface of the water (see p. 205).

## (c) Factors influencing the insect populations

Nuisances from insects in the filter beds develop when, owing to a combination of favourable climatic and other factors, vast numbers of flies develop over a relatively short period. The fluctuation of numbers are difficult to predict on account of the numerous factors involved and the complexity of their interactions, which have formed the basis of several ecological studies. The following are some of the critical factors.

## (i) Temperature

Several of the filter breeding flies have rather low temperature thresholds, a few degrees above freezing, and can breed successfully at 5–10°C (40–50°F). Nevertheless, development and proliferation are slow during the winter and greatly accelerated by warm spells in summer.

In hot weather, on the other hand, drying of the upper layers of the beds may cause downward migration of the predaceous *M. longitarsus* larvae and death of pupae and eggs. This will reduce all fly population.

## (ii) Loading of filters

By the 'loading' of a filter is meant the product of the concentration of organic impurities times the rate of application. The growth of the biological film in the surface layers of the filter and also the rate of proliferation of *Psychoda* increases with the load. On the other hand, most of the chironomids breed for preference in clean, lightly loaded filters. *Anisopus fenestralis* occurs in both heavily and lightly loaded filters.

## (iii) Characteristics of filters

In general, fewer flies emerge from finer than coarser grades of filtering medium. Also, in proportion to the amount of sewage treated, fewer flies emerge from alternating double filters than from continuous action single filters.

TABLE 13 Total development (in days) of different flies breeding in sewage filter beds

Temperature		Species				
		<i>Psychoda</i>		<i>Metriocnemus</i>	<i>Spaniotoma</i>	<i>Anisopus</i>
°F	°C	<i>alternata</i>	<i>severini</i>	<i>longitarsus</i>	<i>minima</i>	<i>fenestralis</i>
37	3	(a)	90	243	260	—
45	7	140	60	153 (b)	103	—
50	10	80	36	94	80	88
59	15	35	26	49 (c)	43	—
68	20	22	(a)	26	29	35
77	25	16		—	(a)	—

(a) did not complete development; (b) 6°C; (c) 16°C.

*(iv) Competition*

Some of the interspecific competition is due to actual predation. Thus *Metriocnemus longitarsus* is a powerful predator in the upper layers of the filters. In filters where *Metriocnemus* and other chironomids are absent (perhaps because of long rests of the filters) *Psychoda* larvae tend to be more numerous.

Other competition is merely for the available food and may be accidental, as in the dislodging of biological film by activity of the worm *Lumbricillus*.

*(v) Time of year*

The prevalence of various species at different times of the year is dependent on all of the foregoing factors. The most serious nuisance is, perhaps *Psychoda alternata*, outbreaks of which occur mainly from June to August. Trouble from *Anisopus fenestralis* or *Psychoda severini* usually occurs earlier, from April to July. The chironomids are most abundant, as a rule, in the autumn, from August to October.

**(d) Control of filter fly outbreaks**<sup>(10, 12, 13)</sup>

Unfortunately there is no simple way of preventing sewage fly outbreaks by suitable management of the filters. Usually it is impossible without a large expansion to alter the load in works liable to outbreaks. It is, of course, possible to alter the size of the filtering medium and use a small granular material. But during the winter, when the insects are not very active, the growth of fungus tends to clog fine filtering medium and lead to 'ponding'.

A simple control method can be employed using insecticides. After a considerable amount of experimentation, involving large-scale trials, it has been decided that the most satisfactory treatment is *gamma* BHC applied at the rate of 1 lb per acre. The insecticide, in the form of a dispersible powder, is mixed with water and introduced into the sewage line running to the filter sprinklers. After application, the filter is rested for as long as possible (at least an hour or two). Weekly applications may be necessary during the fly outbreak seasons. Care must be taken that the effluent is not toxic to fish; but at this rate of dosage the risk is exceedingly small.

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# 13 · *Clothes moths and carpet beetles*

## I · THE ORIGIN OF FABRIC PESTS

Several insect pests with biting mouthparts, which occur in houses, will occasionally bite holes in fabrics; they include cockroaches, crickets and bristletails. The reason for this destructive habit is unknown, for the fabrics attacked do not serve as nourishment. Accordingly, any type of fibre, whether natural or artificial, may be damaged.

This type of sporadic indiscriminate attack is quite distinct from the actual feeding on woollen cloth (or fur, or feathers) by the larvae of certain insects. This seems to have originated as follows.

Before the advent of man, certain small moths and beetles had found a useful role in the economy of nature by acting as scavengers. They utilized as food the more indigestible portions of animal cadavers; the fur and feathers which were neglected by other animals. Another natural breeding site was the neglected nests of birds or lairs of animals, where miscellaneous organic waste, such as fur and feathers, food debris and excrement, would be present. The insects become a nuisance to man when they turn their attention to hides, skins, furs and feathers used in clothes, furnishings and other human belongings.

The insects concerned are the clothes moths (Tineidae), house moths (Oecophoridae) and carpet beetles (Dermestidae). The species concerned possess the unusual ability of digesting keratin, the chief constituent of fur, wool and feathers.<sup>(20, 26)</sup> Keratin is a scleroprotein, consisting of helical polypeptide chains, linked together by cystine groups. Before such molecules can be attacked by proteinases, the —S—S— bonds of the cross-linkages must be broken and the chains set free. This is achieved in the gut of the clothes moth by highly alkaline conditions combined with an extremely low oxidation-reduction potential (maintained by a sparse tracheal system which keeps down the oxygen supply). Under these conditions the chain links are broken, thus:



(This digestive process forms the basis of a method of mothproofing. See pp. 361-362.)

While clothes moths, house moths and carpet beetles are exceptional in their ability to live on wool, they are by no means restricted to this diet. They have been recorded as breeding on a wide variety of dry materials of high protein content, both of animal origin (fish meal, albumen) or of vegetable nature (e.g. cereals). Furthermore, laboratory experiments have shown that they can thrive on many such substances better than on wool, fur or feathers. One must suppose that their association with animal fibres is the exploitation of an ecological niche where there is little competition and that this choice is maintained by the habits of the adults.

One more comment on this type of diet may be added. Pure keratin is very

deficient in certain important amino acids. Furthermore, keratin fibres contain little or none of the vitamin B complex, which are necessary for insect development. In natural breeding sites (bird nests; cadavers) these may be supplemented by miscellaneous contamination. In contrast, the scoured wool or cleaned fur used by man, forms a very sparse diet. It is notable that the parts of garments most liable to successful attack by clothes moth larvae are places stained with sweat (or even more favourable, urine). These contaminants may supply some of the missing food requirements. In artificial (laboratory) colonies of clothes moths, addition of yeast to woollen cloth will very greatly favour development, for the same reason.

## II · CLOTHES MOTHS AND HOUSE MOTHS

### (a) Historical notes

That clothes moths are long-established pests of the household is shown by familiar references to them in ancient times. They were mentioned by Aristotle and Pliny, for example, and also in the Bible, thus:

... as a rotten thing consumeth, as a garment that is moth eaten. – Job xiii. 28.

For the moth shall eat them up like a garment, and the worm shall eat them like wool. – Josiah li. 8.

In medieval times, the words moth-eaten occur in a derogatory sense, thus:

Whatsoever is not stuffed full of mought-eaten terms. – Ralph Richardson's (1551) translation of Moore's *Utopia*.

### (b) Distinctive characters

The Lepidoptera which are liable to damage woollen materials in Britain belong to two families, the Tineidae and Oecophoridae. They are small moths with narrow wings bordered with long hair fringes. Their colouring is shining buff or mottled brown and cream. The genera and species concerned are:

#### Tineidae

*Tineola bisselliella* (the common clothes moth)

*Tinea pellionella* (the case-bearing clothes moth)

*Trichophaga tapetzella* (the tapestry moth)

#### Oecophoridae

*Hofmannophila pseudospretella* (the brown house moth)

*Endrosis sarcitrella* (the white-shouldered house moth)

These may be distinguished by the keys in the Appendix (p. 448).

### (c) Life histories

1. The common clothes moth (*Tineola bisselliella*)<sup>(17, 21, 22, 23, 27)</sup> (Fig. 40)

#### (i) Oviposition

Eggs are laid by both mated and unmated females, but none of the unfertilized eggs hatch. The female may begin oviposition within a few minutes after copulation. She displays characteristic flickering movements of the ovipositor and occasional jerks of the abdomen, interspersed by a few steps forward now and then. The

ovipositor is rubbed against the ground, possibly testing it for suitable places to lay the eggs. When fabric is present the moth will push the eggs in among the fibres. In an otherwise bare container, the eggs will be thrust up against small objects; but in the absence of these, they are scattered at random. There is no evidence to show that any insecticide will repel clothes moths to the extent of preventing them ovipositing on cloth.

### (ii) Eggs

When they are laid, the eggs are damp and slightly sticky and will adhere to any surface, but they are not tightly fastened and are easily dislodged by shaking or brushing.

The egg is roughly oval (about  $0.53 \times 0.3$  mm, weight 0.26 mgm) and covered with a reticular pattern of ridges visible under good magnification.

Inside the egg, the larva develops as a U-shaped embryo. Hatching is achieved by biting an irregular hole in the shell, the whole process of escape taking 10–30 minutes.

### (iii) Larva

The newly hatched larva measures about 1 mm long and 0.2 mm wide. Most of the body is creamy white, sparsely beset with bristles. The hardened head capsule is a light golden brown. The general form is shown in Fig. 37*d*. In the course of development, the larva grows to a length of about 10 mm and the head becomes darker in colour; otherwise there are no great changes in appearance.

The larva bears short antennae on the head but no eyes (ocelli); nevertheless, they are able to distinguish the general direction of a source of light. They crawl away from the direction of illumination and, if placed on top of a piece of cloth, will tend to crawl underneath it.

The mouthparts are modified for biting the food and for spinning silk. The mandibles are strong, ridged, cutting organs. On the inside of the labrum and of the maxillae are spines to assist in grasping the food. When, as usually, the larva is feeding on fur or woollen fibres, its usual procedure is to bite off a fibre at a convenient point and reject the loose end. After a few bites at the stump, the larva often moves on to another fibre, thus leaving a trail of damaged hairs and destroying more than it consumes.

Apart from fur and wool, many substances can form larval diets, some of them being highly suitable; examples are meat- or fish-meal, egg albumen and various cereals.

Well-grown larvae may bite holes in many fabrics which they cannot digest and sometimes small quantities of inedible materials (cork, cotton wool, beeswax) may be actually swallowed. Nevertheless, the larvae are able to discriminate between animal and vegetable fibres; in a mixed textile only woollen fabrics are eaten and cotton is left.

Some kinds of animal fibre are too coarse to be attacked by young larvae whose mandibles only span about  $90 \mu$ . Pig bristles and horse hair are too wide to be bitten whereas wool fibres ( $10\text{--}100 \mu$ ) are readily attacked.

Digestion is evidently slow, for the food moves slowly through the intestine. (Starved larvae expel no faeces for two days after being re-fed.) This slow rate of digestion is probably due to the difficulty of coping with keratin, which is sometimes excreted partly unchanged.

The midgut is alkaline but the hindgut is acid owing to the presence of acid ammonium urate, which appears to be the main vehicle for elimination of nitrogen. Sulphur (from cystine) is excreted in the form of sulphates and melanin passes through unchanged.<sup>(20)</sup>

The larval silk glands are located in the head and thorax and the silk emerges from a tube or 'spinneret' beneath the head. The diameter of the silk varies with the size of the larva, being of the order of one-tenth to one-twentieth the diameter of white wool. The average amount of silk spun by 500 larvae in a week was found to average 0.1 mgm each, which was 1.7% of the mean body weight.

The larvae of *Tineola* may crawl about naked and unprotected, but very often they spin themselves frail tubes of silk, open at both ends, in which they can move freely back and forth. Or the silk may be spun as a flattened tent under which they can crawl about. Small pieces of fibre and other debris are usually woven into the webbing.

The larvae also make tough cylindrical cases in which they retire to moult or for resting periods. These cases are quite different from the straggling galleries or the smooth, portable cases made by *Tinea pellionella*. They have an untidy look owing to the incorporation of a great deal of miscellaneous debris (particles of food material, excrement and cast skins) which makes excellent camouflage. But inside they are smoothly lined with silk.

There are the usual three pairs of legs ending in claws on the thoracic segments and prolegs on four abdominal segments, each proleg bearing a circle of hooklets. On smooth surfaces the larvae are dependent on spinning a silken web on the surface to provide a grip for these claws and hooklets.

The minimum number of moults in the larval period is five; but various circumstances may increase the number and as many as 40 have been observed. Pupation occurs in one of the tough cocoon-like moulting cases and the last larval skin may be found at the bottom of the case.

#### (iv) Pupa

The pupae of *Tineola* vary very much in size, ranging from about 4 to 7 mm in length (3 to 10 mgm weight).<sup>(23)</sup> In form the pupa differs slightly from most Lepidoptera in that the appendages, though fused to the body, are free at the tips; and more than three of the abdominal segments are mobile. On the posterior dorsal margins of the abdominal segments IV to IX are comb-like rows of hooklets which assist the larva to emerge.

Before emergence, the adult in the pupal cuticle wriggles forward and, bursting its cocoon, projects out of it. Afterwards the pupal skin is left sticking out of the empty cocoon. The wings of the newly emerged adult take from 10 to 30 minutes to expand and afterwards they are held vertically upwards for a further 5 to 20 minutes. Meanwhile, the moth excretes a few drops of accumulated faeces.



FIG. 40. History of the clothes moths. (a) eggs; (b) larva in silk tunnel; (c) pupa wriggling out of the pupa case before emergence of (d) the adult. All of *Tineola bisselliella*; (e) larva of *Tinea pellionella* in its characteristic case. (Original.)

*(v) Adult*

The size of the adult, like that of the pupa, is very variable and depends on the amount of food taken in larval life. Normally the moths measure about 10 to 15 mm wing span and 6 to 8 mm long when at rest with the wings folded. The colour is a shining golden hue and distinguished from *Tinea* as described in the key (p. 453).

The body is entirely and densely covered with scales of which there are about half a dozen different kinds. The size of the head is exaggerated by erect scales. The antennae are thread-like, of an indefinite number of joints. The mouthparts are greatly reduced and are functionless; tiny mandibles and maxillae are evident but there is no coiled sucking tube formed from the maxillae as in most Lepidoptera.

The thoracic region is covered with fine scales. The scales on the legs give them a characteristic appearance; at each joint there is a sleeve-like projection of scales which tends to become belled or ruffled by walking. The feet bear claws and there are also spines on the mid- and hind legs, presumably to aid in walking.

The borders of the wings are beset with fringes of long hairs which increase their effective surface area. The ratio of the wing surface to fringe surface is about 2 or 3 to 1. The wings are coupled together by bristles (6-8 in the male, 2 in female) overlapping one strong dark seta.

The adult moths have three methods of progression: flight, running and jumping.

*Flight.* Only males and dwarf females (resulting from inadequate larval food) fly voluntarily. The speed of flight is about 50 to 70 cm per second. If normal females are launched into the air, they flutter down to the earth. Observations on a number of moths show that the larger ones have proportionally less wing area (doubling of the body weight only resulted in 30% wing increase).

Thus although a few females occasionally fly, it is the larvae and running females which are mainly responsible for spreading infestation. In one experiment, a piece of clean wool was suspended above a heavy moth infestation in a chest and it remained uninfested for a whole season.

*Running.* Moths very frequently make use of this means of locomotion, travelling at the rate of about 10 to 30 mm per second.

*Jumping.* This is characteristic of males and is rarely observed among females. The spring is given by the hind legs and the wings give one or two beats.

Decapitation does not prevent normal running, jumping or flying, but headless moths will not initiate these movements spontaneously.

*Copulation.* The males flutter round the females which remain largely passive, except for occasional protrusion and retraction of the ovipositor. The sexual excitement of the males is enhanced by scent which is given off from the abdomen of the female. A single female will elicit response at a distance of only 1.5 cm, but several females can be perceived by the males at rather longer distances.

Copulation is effected by the male twisting his abdomen round so as to make contact with the tip of that of the female. When union has been effected, the male usually moves round to the linear position (heads pointing in opposite directions). Copulation lasts about 15 minutes. Sometimes the pair are unable to separate and remain connected until they die.

2. The case-bearing clothes moth (*Tinea pellionella*)<sup>(3)</sup>

This moth is less common than *T. bisselliella* and it has received less attention from biologists. In general, its life history is not very different.

(i) *Oviposition*

Females begin to lay eggs 1 to 6 days after emergence. The eggs are laid singly on, or inside, the folds of woollen fabrics, where these are available.

(ii) *Eggs*

The egg of *T. pellionella*, though about the same size as that of *Tineola bisselliella*, can be distinguished by its longitudinal ridges (visible on magnification); whereas that of *Tineola* has a reticular pattern.

(iii) *Larvae*

The newly hatched larva crawls about on the food material for 24 hours; after this, it settles down to make the case, which gives it its popular name. The case (Fig. 40e) is shaped somewhat like a pillowcase, open at both ends; and the larva can turn round and feed from either end. The case is constructed from pieces of fibre, bitten off by the larva, and bound together with silk. Sometimes the external appearance is rough, but it is smooth inside. The case is somewhat flattened and never fastened to the surface; from all these points it is easily distinguished from both the meandering galleries and the rough oval pupa cases made by *Tineola*.

The fore-part of the larva emerges from the case, which is carried about with the larva as it moves; the fore-part is stretched out and then the rear, covered by the case, is pulled up afterwards. In spite of this, the larva can move about as fast as the larva of *Tineola*, that is, about 2–3 cm per minute.

Normally, larvae of *T. pellionella* never abandon their cases and, if the case is fastened down, the larva will struggle to pull it along for about half an hour before abandoning it; but a new case can be spun overnight if necessary.

As the larva grows, it enlarges its case by inserting a V-shaped patch into a longitudinal incision. The progress of enlargement during larval life can be illustrated by placing them successively on fibres of contrasting colours which are then woven into succeeding areas of the case.

As with the common clothes moth, there are a minimum of five larval instars; but the number can be increased by unfavourable conditions.

(iv) *Pupae*

Before pupation, the larva wanders away from the food material and, finding a suitable niche, fastens its case down to the substrate, by silken threads. One end of the case is also closed and the larva rests inside and finally casts its skin and pupates. The pupae are pale yellow at first, darkening to brown; about 4 to 5 mm long.

At the time of emergence, the pupa wriggles partly out of the case and, when the adult has emerged, the pupal shell remains protruding from the old case.

*Adult.* The colour of the wings is darker than that of *Tineola* and they are marked by three rather indistinct dark spots on the forewings. In general the moth

is not unlike *Tineola* in appearance and size, the distinguishing characteristics being given in the key (p. 453).

The mouthparts of the adult are fairly primitive in that, like those of *Tineola*, they include vestigial mandibles. There is a trace of the coiled sucking tube (formed by processes of the maxillae) which is the normal feeding mechanism of most Lepidoptera; however, it is non-functional and the adult does not feed, but lives on reserves accumulated during larval life.

### 3. The tapestry moth (*Trichophaga tapetzella*) (Fig. 57a)

This is a larger moth than the two clothes moths. The larva is about 14 mm long when fully grown and the adult has a wing span of about 22 to 25 mm. The larvae form tunnels in the infested material lined with silk and incorporating many bitten-off fibres. In making such galleries they damage a considerable amount of the infested fabric. They feed on such things as carpets, horse blankets, tapestries, felting, furs and skins and the larvae are able to attack rather coarser fibres than those damaged by the more common clothes moths. Upholstered furnishing may also be consumed.

The larva forms itself a very rough pupa case (like *Tineola*) and the adult has the same habit of partly wriggling out in its pupa case before emergence so that empty cases may be found with the pupal skins still protruding from them.

The adult holds its wings at a roof-like angle over the back like the other *Tineids* and in contrast to the *Oecophorids* which hold their wings folded flat over the back.

### 4. The house moths (*Hofmannophila pseudospretella* and *Endrosis sarcitrella*)<sup>(4, 15, 28, 29)</sup> (Figs. 57g & o)

The house moths are probably species which originated as feeders on dry vegetable matter and have become adapted to dry animal remains, including hair or wool. As pests, they can infest and damage stored food (see p. 320) or, in some cases, they will feed on wool clothing and carpets. *Endrosis* tends to be more of a food pest and *Hofmannophila* more of a scavenger and more likely to attack fabrics. Mixed infestations not infrequently occur. Their biology has been studied on cereals; but both species have been reared on wool dusted with yeast, so that they can probably digest keratin.

#### (i) Oviposition

The eggs of *Hofmannophila* are laid singly, quite freely, though with some preference for rough surfaces. *Endrosis* females lay reluctantly in captivity and prefer to insert the eggs into fine crevices.

#### (ii) Eggs

The eggs of *Hofmannophila* are oval, hard and shiny, not sticky when laid, about 0.5 to 0.6 mm long. The eggs of *Endrosis* are dull white, sticky and adhere together, about 0.55 mm long.

(iii) Larvae

Larvae may be distinguished by the key in Appendix (p. 452); in addition the following points may be noted.<sup>(13)</sup>

The larvae of *Hofmannophila* are white and glossy and, when fully grown, reach a length above 16 mm (weight 50–108 mgm (Fig. 37c)). Those of *Endrosis* are dull white and seldom exceed 14 mm (10–20 mgm). Both species burrow in the food material, forming a silk tunnel. They emerge and wander away to pupate.

(iv) Pupae

Both species form rough cocoons incorporating debris. If these cocoons be torn open, both are found to be rather tough. But that of *Hofmannophila* is brittle and tears like brown paper exposing the pupa lying loosely inside; whereas that of *Endrosis* tears like cotton wool and the pupa is closely invested with the innermost layers.

(v) Adults

Adults of the two species are quite distinct (see Appendix key, p. 451). In mixed cultures they have been seen copulating together but without producing progeny. Both forms (but especially *Hofmannophila*) are occasionally seen in houses, sheds and attics.

TABLE 14 *Rate of development of clothes moths and house moths at different temperatures*

Insect	Stage	Period in days				
		13°C	15°C	20°C	25°C	29–30°C
<i>Tineola bisselliella</i>	Egg	37	24	10	7	6
	Larva	?	186–195	123–135	72–89	62–72
	Pupa	52	35	18	12	10
<i>Tinea pellionella</i>	Egg		—	4·5*	5	7
	Larva		—	46*	33	48
	Pupa	—	—	18·5*	10	10
<i>Hofmannophila pseudospretella</i>	Egg	42	25	14	9·8	10
	Larva	145	126	78	71	
	Pupa	56	48	25	15·5	13
<i>Endrosis sarcitrella</i>	Egg	23	15	8·6	6·3	6·8
	Larva	102	73	42	38	
	Pupa	31	25	15	10·4	7·4

\* at 21·5

Humidity: 70% R.H. for *Tineola*, 90% for other species. Foods: Wool impregnated with infusion of horse dung for *Tineola*; wool plus yeast for *Tinea*; wheat ‘middlings’ for other species. Data from TITSCHACK, E. (1925) *Z. wiss. Zool.* **124**, 213; CHEEMA, P. S. (1956) *Bull. ent. Res.* **47**, 167; WOODROFFE, G. E. (1951) *Bull. ent. Res.* **41**, 529, 749.

It should be noted that the diet for *Tineola* was rather unfavourable. On a good diet, larvae can develop in 45–50 days at 25°C.

(d) **Quantitative bionomics**<sup>(21, 22, 23, 24, 28, 29)</sup>

In assessing the effects of environmental factors on developing stages of clothes moths and house moths, a favourable influence will be indicated by short development and a high percentage emergence as adults. A favourable influence on the adults should promote long life and fertility.

(i) *Temperature* (Table 14)

For two of the developmental stages, the egg and the pupa, temperature is virtually the only important environmental factor. (See Fig. 8, p. 57.)

Eggs of *Tineola*, *Hofmannophila* and *Endrosis*, hatched at the lowest temperatures tested (12.8°C; 55°F, and 10°C; 50°F). On the other hand, *Tinea* eggs failed to hatch at 14°C (57°F). At the upper limit *Tinea* hatched at 32.5°C (99°F) and *Tineola* at 30°C (86°F), but 29°C (84°F) was the limit for the house moths. Between the extremes, temperature had the usual accelerating effect, except near the upper limit, where a slight prolongation was evidence of a harmful influence.

The effects of temperature on larval and pupal development of these moths was largely similar to that on the egg stage, except that the upper limit for larval development was a little lower.

Larvae of *Hofmannophila*, however, tend to enter a diapause (see p. 57) when fully grown, especially if they have been reared under warm (summer) conditions. This diapause prior to pupation adds a considerable, indefinite, period to the figure for larval development for this moth in Table 14. It appears that the favourable temperature range of the clothes moths is slightly higher than that of the house moths. Within the range of possible development, it appears that the slower development at cool temperature produces heavier adults.

Adult life is curtailed by high temperature in all species, thus (in days): *Tineola*, 10–13 at 20°C (68°F), 5–6 at 30°C (86°F); *Tinea*, 6.6 at 22°C (71°F), 5.2 at 26.5°C (78°F); *Hofmannophila*, 19 at 15°C (59°F), 12 at 25°C (77°F); *Endrosis*, 16 at 15°C, 5 at 25°C.

(ii) *Humidity*<sup>(7)</sup>

The larval stages of the clothes moths, both *Tineola* and *Tinea*, can develop at humidities down to 20–30% R.H. On the other hand, the rate of development is much prolonged at low humidities. The optimum for *Tineola* is about 75% R.H. The two house moths will only complete larval development at humidities above 80% R.H.; and 90% R.H. appears to be optimum.

Low humidity somewhat curtails adult life. Thus at 25°C (77°F) in days: *Tineola* (males) 32 at 75% and 23 at 20% R.H., (females) 20 and 14 days respectively. *Hofmannophila* (females) 12 at 70%, 9.4 at 20%. *Endrosis* females live longer if allowed access to water.

(iii) *Food of larvae*<sup>(24)</sup>

A wide range of larval food materials has been investigated, especially with *Tineola*. The results are not very easy to interpret briefly, because the two criteria of a good diet (rapid development and high percentage adult emergence) do not always agree.

On a sparse diet, development is greatly prolonged and the number of moults increases.<sup>(17)</sup>

Woollen cloth sprinkled with yeast was found to be a very satisfactory diet for the clothes moths and also reasonably satisfactory for the two house moths. Apparently all species are able to digest keratin. Nevertheless, supplementary vitamins are highly desirable, because wool (raw or scoured), fur and feathers by themselves were unfavourable even for the clothes moths. Fish meal formed a satisfactory breeding material and larvae were also able to develop on dead insect remains. Cereal products (e.g. flour) were satisfactory if not extracted or if vitamins (yeast, etc.) were added.

*(iv) Longevity and fertility of adults*

As already noted, high temperature and low humidity curtail the life of the adult moths. But under any given conditions, their longevity and egg production depend to a large extent on their size, which in turn depends on larval life. Thus, with *Tineola*, females about 6 mgm weight averaged 106 eggs each, as compared to 55 eggs from 4 mgm females, or 27 eggs from 2 mgm females. Analogous results are recorded for *Tinea*, *Hofmannophila* and *Endrosis*.

**(e) Natural enemies<sup>(6)</sup>**

*(i) Predators*

Probably the most important predator of *Tineola* is the larva of the window fly *Scenopinus fenestralis* (Fig. 41), which attacks the larvae. The mite *Pyemotes ventricosus* (Fig. 31 and p. 333) attacks newly emerged adults as well as early stages.

Laboratory culture of *Hofmannophila* have been troubled by the mite *Cheyletus eruditus* (Fig. 39i and p. 333), which destroys eggs and newly emerged larvae.

*(ii) Parasites*

Various hymenopterous parasites have been observed to attack clothes moth larvae, including *Apanteles carpatus*, *Meteorus cespitator*, etc.

*(iii) Micro-organisms*

The common clothes moth *Tineola* suffers from two types of disease: polyhedrosis, due to a virus, and protozoan infections.

Polyhedrosis may occur to different degrees in laboratory colonies. The signs are loss of appetite, sluggishness and a dull white appearance. Finally the larvae become swollen, the skin rupturing at a touch and exuding a cloudy liquid. The disease can exterminate colonies.

The protozoan infections are rather less prevalent and less serious. Two protozoan parasites have been recorded: *Adelina masnili*, a coccidian, and *Nosema* sp., a microsporidian.

**(f) Importance**

A survey of losses due to moth damage was conducted in 1948. About 26% of ordinary households were found to have suffered some moth damage in the previous

15 months. At a fairly conservative estimate the total loss in the country worked out at £1.5 million (a figure which would need to be increased to correspond to present-day prices).<sup>(18)</sup>

The most important of the clothes moths, in regard to damage of domestic clothing and furnishings, is *Tineola bisselliella* followed by *Tinea pellionella* and *Hofmannophila pseudospretella*.

Materials damaged by the clothes moths include many kinds of fur, any woollen clothing or furnishing (but especially carpets and blankets), fabrics made with other animal hair (alpaca, camel), baize, felt used for insulation or piano hammers, feather stuffings, skins of animals and other museum specimens. Clothes moth larvae damage far more than they actually consume, owing to their wasteful feeding habits and to utilization of fibres in making cocoons. Moreover, the mere severing of threads in a fabric may cause weak patches or even holes and in the same way the pile of carpets or of velvet upholstery may be loosened and fall out leaving small 'bald' patches.

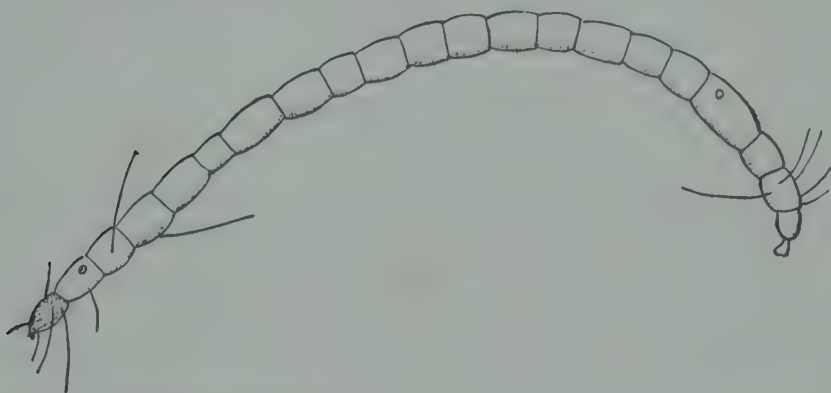


FIG. 41. Larva of *Scenopinus fenestralis*,  $\times 5$ .

As already mentioned, clothes moths only thrive on woollen fabrics which are somewhat soiled and also they require undisturbed conditions, preferably in partial darkness. Where an infestation exists in some corner of a house, it represents a constant threat to all other susceptible articles. Thus eggs laid on perfectly clean fabric produce larvae which may find it difficult to grow and develop. Even a small and unsuccessful colonization will cause holes which seriously spoil whole garments.

The tapestry moth, *Trichophaga tapetzella*, is less successful in human dwellings, but it is able to breed in coarser materials than the clothes moths. Among other places it is encountered in stables and harness rooms, where it breeds in soiled horse blankets and formerly often damaged coach upholstery.

The house moths (which have been mentioned as food pests; p. 320) have been described as rubbish feeders; they breed in dried animal or vegetable matter. Both species are very common in the nests of various species of wild birds. Sheds, barns and other outhouses are another favourite breeding ground from which the adults often fly into human dwellings; and upon occasion they may cause damage to carpets or upholstery.

### (g) Control

There are two aspects to the control of clothes moths: eradication and prevention. The destruction of an existing infestation (often after much damage has been done) is comparatively easy. Prevention, however, which is much more desirable, is considerably more troublesome.

#### (i) *Destruction of clothes moth infestations*

Fumigation is a satisfactory way to eradicate an infestation of clothes moths. Small articles (clothing, furs, etc.) may be simply treated in any convenient container such as a suitcase, trunk or chest. A variety of organic liquids can be used the chosen fluid is poured over the clothing fairly liberally (say  $\frac{1}{2}$  pint per 10 cu ft) and allowed to give an exposure for about 6 hours, or overnight.<sup>(11)</sup>

Where a widespread infestation of clothes moths has developed, for example among a lot of stored upholstered furniture and carpets, it may be necessary to resort to van fumigation. Hydrogen cyanide, as used against bed bugs is the most efficient treatment. Or possibly the cheaper and simpler, but less reliable, sulphur fumigation might be tried.

#### (ii) *Preventive measures*

Both adults and larvae of clothes moths avoid the light and the eggs are easily dislodged from furs and fabrics by shaking or brushing. Therefore infestations are mainly prone to develop in materials left undisturbed in dark and shady places. Clothes lying in drawers or cupboards (especially furs or woollen winter garments put away for the summer), furniture in storage, or in seldom-used and rarely cleaned rooms, are especially liable to attack.

The first line of defence against the moth is constant vigilance for signs of attack. Unless reliable precautions have been taken, stored furs and woollen fabrics should be periodically examined for signs of damage. It is also very important to take special care of susceptible articles that are to be put in storage. The precautions which may be taken are as follows:

#### *Cleansing*

Furs and garments to be put in storage should be thoroughly brushed and shaken to remove any moth eggs which may have been laid on them. Unless other precautions have been taken, this shaking and brushing should be repeated periodically during the period of storage.

Fabrics and clothing generally should be dry-cleaned if possible, since the presence of grease stains is favourable to the development of an infestation.

Regular household cleaning with brushing of furniture and carpets will tend to discourage moths attacking furniture. Areas of carpet inaccessible to these cleansing measures (e.g. under low cupboards, etc.) are liable to attack.

#### *Mechanical barriers*

One simple method of protecting garments from moths is to make sure that they are uninfested and to store them in large bags of stout paper or plastic. If the bag is unbroken and properly sealed by folding, it will prevent access of the moths.

Fairly efficient protection of such things as blankets can be achieved by folding them in large sheets of paper. Good quality newspaper can be used, though the idea that the newsprint has some additional mothproofing value is, unfortunately, fictitious.

### *Insecticides*

Vaporizing solid insecticides made up into 'moth balls' have been in use for many years to prevent clothes moth damage. One of the earliest substances employed for this purpose was camphor; more recently naphthalene and paradichlorobenzene have been used, the latter being the more efficient.<sup>(10)</sup>

These odoriferous substances are often described as moth 'repellents' but there is no good evidence that the mere odour of any substance will drive away moths.<sup>(1)</sup> Insecticides of the moth ball type act merely as fumigants and therefore they can only be relied upon in nearly air-tight containers. However, they may be found useful in suitcases, trunks and chests used at the rate of 46 gm per cu ft of naphthalene or 12 gm per cu ft of paradichlorobenzene. It must be realized, however, that unless hermetically sealed up, these substances will evaporate away, in proportion to their volatility. (Paradichlorobenzene, though more potent, is considerably more volatile than naphthalene.) In recent years, the highly effective modern insecticides *gamma* BHC and heptachlor have been used in the same way, in crystalline form. They are much more effective and, at 5 gm per cu ft, have given as much as 5 years' protection of crated furniture, as compared with 1 year's persistence of naphthalene (at 46 gm per cu ft). Since it may be undesirable to scatter these insecticides over furnishings in substantially pure form, they may be used adhering to cardboard sheets. The crystals are simply scattered over the cardboard after applying a layer of quick-drying adhesive. The treated cards, placed among furnishings (to give the 5 gm crystals per cu ft) have given good protection from carpet beetle larvae, which are likely to be more tolerant than clothes moth grubs.<sup>(2a)</sup>

### *Cold storage*<sup>(2)</sup>

For the protection of valuable furs in the summer months, it is the practice in many large towns to put them into large commercial refrigeration vaults which are maintained at a cool temperature (about 5°C or 40°F). This does not destroy any eggs or moth grubs that may be present, but it prevents the eggs from hatching and the grubs from feeding. Therefore no damage can occur during cold storage. The method is quite reliable but rather expensive.

### *Mothproofing*<sup>(8)</sup>

The mothproofing of furs or woollen fabrics involves treating them in some way so that clothes moth larvae cannot feed on them.' The ideal treatment should be permanent, imperceptible, resistant to washing and dry-cleaning and compatible with dyeing and bleaching and other processes of textile manufacture. The credit for the earliest conception of making fibres immune to moth damage seems to belong to two Americans who, in 1887, took out a patent for moth-proofing curled hair. In subsequent decades the subject has received much attention from technologists; and there are thousands of patents for various processes.

The various methods may be grouped into three categories: (1) Impregnations of stomach poison insecticides. (2) DDT impregnation. (3) Treatments rendering wool indigestible to clothes moth larvae.

(1) *Impregnations of stomach poisons.* The principle involved in this method is simply to add a poison which kills the moth grubs when they begin to feed on the treated fibres. (The amount of damage they can do before being killed is negligible, with an efficient treatment.) As early as 1905 it was noted that eosin was toxic to clothes moth larvae and subsequently a number of dyestuffs were examined for this property by the German firm of Bayer. However, the only dye found to be promising in early years was Martius yellow (2,4-dinitro- $\alpha$ -naphthol) which is still used for certain purposes. More progress was made with colourless compounds, especially fluorides and silico fluorides. A series of these was marketed by another German chemical company, the I.G. Farbenindustrie, in the 1920s, under the general name 'Eulan' (Eulan W, M, NK, NKF, etc.).<sup>(9)</sup> These were usually applied at various stages in the dyeing processes, but they were never entirely successful since they were leached out by ordinary laundering. Other treatments of the same order of efficiency depend upon pentachlorophenol and on formaldehyde applied in an acid bath. Other insecticides, soluble in organic liquids, can also be used; for example cinchona derivatives (fatty acid salts of the alkaloids) or such compounds as lauryl pentachlorophenol.

A very considerable advance was made in the following decade when compounds were employed which, though colourless, behaved like good dyes in having a strong affinity for the wool fibres. They were therefore fast to washing and a few were found to be sufficiently toxic to moth larvae to act as proofing agents. In particular the later forms of Eulan (Eulan N and CN) and Mitin FF should be mentioned (see p. 96).

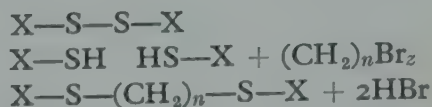
(2) *Impregnation of contact poisons.* In the early 1950s, mothproofing of garments was offered as a regular service by many dry cleaners. Impregnation was achieved by dipping in dry-cleaning liquid containing DDT (or lauryl pentachlorophenate). 0.2% DDT on the garment weight gave good results;<sup>(25)</sup> but the effect was slowly lost after washing or immediately after ordinary dry cleaning. By the 1960s it appears that this type of moth proofing had become obsolete.

At present, the only impregnation of this type, which is extensively employed and apparently safe and reliable, is the impregnation of dieldrin by the Dielmoth process. By this method, the dieldrin is applied under standard conditions in a hot emulsion and remains bound in the wool fibres more firmly than is possible by impregnation from a volatile solvent. The wool takes up about 0.1 to 0.25% by weight. This treatment is largely employed for carpets and outer garments and not for undergarments or children's wear.

On the retail market, it is possible to buy pressurized aerosol packs containing insecticides for application to woollen garments for mothproofing. Such treatments would be unreliable unless the whole garment was carefully treated. Attempts to protect clothing by casually puffing spray into a cupboard full of clothes are likely to lead to disappointment.

(3) *Rendering wool inedible to clothes moths.* It has been mentioned earlier (p. 347)

that the digestion of wool by insects relies on splitting the disulphide cross-linkages in the keratin molecules. This can be largely prevented by the following ingenious chemical treatment. The disulphide linkages are broken *in vitro* (by reduction to sulphydryl groups) and then reunited by intercalation of a short hydrocarbon chain, thus:



Molecules with these new cross-linkages are more difficult for the insect to digest and the physical properties of the wool are not greatly affected.

*Moth-proofing tests.* In order to introduce standard comparisons between estimates of moth-proofing value based on work in different countries, the International Wool Textile Organization published a standard test method in 1956.<sup>(5)</sup> This depends on measurement of damage by moth larvae based on weight and adjusted by comparison with proofed material (treated with dinitro- $\alpha$ -naphthol). This method is useful, but somewhat narrow in application (since a particular kind of serge must be used). Other methods are employed in commercial investigations.

### III · HIDE BEETLES (Dermestidae)

#### (a) Historical note

Remains of dermestid beetles have been found in mummies in Egyptian tombs.<sup>(14)</sup> Embalming seems to have been a lengthy process, during which the bodies probably reached the butyric stage of decomposition and became attractive to the beetles. In one case, the beetles (*D. frischii*) were preserved in a glass vessel, presumably because they had emerged from a revered body.<sup>(16)</sup>

#### (b) Distinctive characters

About 700 species of dermestid beetles are known. They are compact, oval or nearly round insects, mostly very convex, and usually rather small (2–4 mm; though a few reach as much as 12 mm in length). The body is nearly always covered with hairs or scales, often of various colours, making up distinctive patterns.

The head is often partly sunk in the thorax and bears a pair of antennae which can be laid back to rest in grooves in the front (or sometimes on the underside) of the first thoracic segment.

The larvae of dermestids are characteristic of the family. They are densely covered with hairs of various lengths and sometimes of different types. Thus the larvae of *Anthrenus* bear bunches of segmented hairs, with arrow-like heads. All the larvae have moderately well developed, five-segmented legs.

#### (c) Recognition, occurrence and life histories of various pests<sup>(12)</sup>

##### *Dermestes*

Over fifty species are known but only two or three are at all common as domestic pests in Britain. The *Dermestes* spp. are rather large members of the family, being

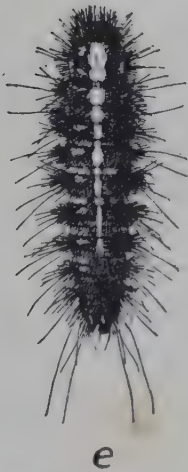
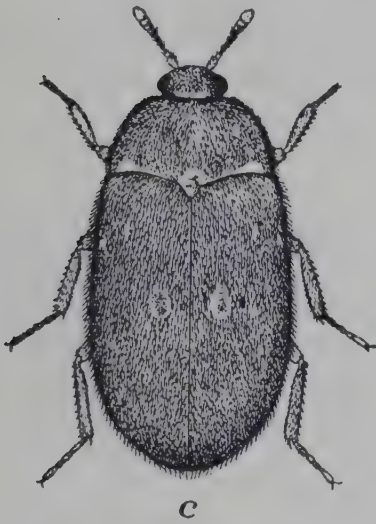


Fig. 42. Dermestidae (carpet beetles). Adults: (a) *Dermestes maculatus*; (b) *Dermestes lardarius*; (c) *Attagenus pello*; (d) *Anthrenus scrophulariae*. Larvae: (e) *Dermestes maculatus*; (f) *Attagenus pello*; (g) *Anthrenus scrophulariae*. After Hinton (1945) Beetles associated with stored products. (Nat. Hist.) (a) & (b)  $\times 6$ ; (c)  $\times 10$ ; (d)  $\times 15$ ; (e) (f) & (g)  $\times 3$ .

from 5.5 to 12 mm in length. They are oblong in shape and densely covered with hairs which are always round, never flattened and scale-like. *Dermestes* can be distinguished from the other genera by the absence of the median ocellus on the head. The two commonest species may be distinguished as follows:

### Adults

- Anterior half of each elytron with a small undulated black mark in the centre of an extensive pale area (Fig. 42b) *D. lardarius* (bacon beetle)  
 Elytra uniformly coloured, black (or, when immature, brown). Apex of each elytron produced backwards into a fine point (Fig. 42a) *D. maculatus* (= *vulpinus*) (the leather beetle)

### Larvae

- Conical processes (spines) on the penultimate segment of the abdomen, nearly at right-angles to the body, curved and placed close together as in a V, the actual tips directed backward; no pronounced median bristle *D. lardarius*  
 Spines sloping to the rear, moderately close together, with the actual tips directed forward; a pronounced median bristle placed slightly behind them (Fig. 42e) *D. maculatus*

### Occurrence

The *Dermestes* beetles breed in dry animal proteins and are common in hide and skin warehouses, bone factories and dog biscuit stores. They sometimes attack dried meats and fish meal in domestic stores but rarely breed in woollen clothes or furnishings unless these are badly contaminated with animal matter. When specimens are often encountered in dwelling houses, the larder should first be examined for the breeding site. Alternatively they may be feeding on a dead mouse or bird in an attic or floor space.

### Life history

The females lay eggs on material suitable as food for the larvae, often in crevices, in skins, hides, etc. The eggs are about 2 mm long, white in colour.

The larvae are whitish when first hatched, but become darker in a few hours, when exposed to light, or in two days, if kept in darkness. They will feed on almost any animal matter which is dry or in a state of decomposition; and vegetable matter is also sometimes consumed. Feeding is continuous and sometimes their faecal pellets emerge joined together in a bead-like chain.

Throughout development the larvae avoid light. They are very active but sometimes if disturbed they will become suddenly immobile, partly curled up, apparently feigning death. Normally there are 5 or 6 moults; but, under rather indefinite conditions, this number may increase to 12. When fully grown, they reach a length of 10–15 mm.

The mature larvae cease feeding and seek a place for pupating. Often they wander away from the foodstuff and excavate holes in quite hard inedible materials. These shelters may be merely a little longer than the larva's body, or they may extend up to a foot in length. The mouth of the burrow becomes choked with debris and

finally with the last larval skin, which is cast off and acts as a protective plug. But if the larvae are forced to pupate in the open, they will usually do so inside the last larval skin.

The boring habits of the mature larvae cause quite a serious economic problem. One of the earliest records of this kind of injury is that referred to in 'The Last Voyage of Thom. Cavendish' (*Hakluyt's Voyages*; ed. Goldsmid, Edinburgh, 1890), where there is an account dating from 1593 of a ship carrying a cargo of dead penguins which sank because of the honeycombing of sides and bottom by dermestid larvae.

In recent times, there are numerous references of damage to crates and boxes and to walls, floors and roofs of factories and stores and sometimes of ships and barges due to these pests.

The adult beetles feed on substances eaten by the larvae, this food being necessary to the female for the maturation of her eggs. The sexes will copulate at temperatures above 16–18°C, usually for periods of 3 to 5 minutes. A single mating is sufficient to allow the female to produce fertile eggs for the rest of her life; but normally she will mate a number of times. After a pre-oviposition period of 10 to 15 days, egg-laying begins and is continuous for 2 to 3 months. The total number of eggs laid varies considerably; 200 to 800 have been counted. The adults may live for over 3 months.

#### *Speed of development*

*D. maculatus*. E at 26–27°C (79–81°F), 3 days; at 23–24°C (73–75°F), 5 days. L at 23°C (73°F), 44 days; P (winter), 35 days; 20–25°C (68–77°F), 14 days; 27°C (80°F), 8–14 days. Total, at 28–30°C (82–86°F), 42–46 days; at 23°C (73°F), 55 days; but may increase up to several years with very unfavourable conditions.

*D. lardarius*. E at 17°C (62°F), 9 days; at 24°C (75°F), 3½ days; at 25–28°C (77–82°F), 2½ days; P, 8–15 days. Total, at 18–25°C (64–77°F), 2–3 months.

#### *Anthrenus*

An obvious feature of the *Anthrenus* beetles is their dense covering of scales of different colours, giving the body a variegated pattern. They are rather small beetles (1.5–4 mm), roughly oval in outline and strongly convex. The antennae lie back in deep recesses on the thorax when at rest. Some of the commoner species may be distinguished as follows:

#### *Adults*

1. Antennae 8-segmented with a club of 2 segments (2–2.8 mm)

*museorum* ('museum beetle')

Antennae 11-segmented with a 3-segmented club (2)

2. Eyes smoothly rounded. Antennal club with nearly parallel sides

*verbasci* ('varied carpet beetle')

Eyes indented on inner side. Antennal club oval

*scrophulariae* ('common carpet beetle') (Fig. 42d)

and

*vorax* ('furniture carpet beetle')

(N.B. *verbasci*, *vorax* and *scrophulariae* show a number of varieties of colour pattern and the last two are difficult to distinguish from each other and from *A. pimpinellae*.)

### Larvae

1. Abdomen with first 8 sternites distinctly sclerotized. Arrow-headed hairs of caudal tufts with heads strongly produced and filiform (2)  
 Abdomen with first 8 sternites entirely membraneous. Arrow-headed hairs with heads not produced apically, never filiform (3)
2. Heads of arrow-headed hairs about 0.17 mm long; basal struts about one-ninth as long as the complete head *scrophulariae* (Fig. 42g)  
 Heads of arrow-headed hairs about 0.10 mm long; basal struts about one-sixth as long as complete head *vorax*
3. Heads of arrow-headed hairs as long as combined length of 4 or 5 preceding segments *museorum*  
 Heads of arrow-headed hairs as long as combined length of 7 or 8 preceding segments *verbasci*

### Occurrence

*Anthrenus* larvae will feed on woollen materials, hair, furs, bristles, leather and skins and on insect specimens. (*A. verbasci* and *A. museorum* are the worst pests of dried insect specimens.) They are not serious pests of carpets except where these are kept tacked down and undisturbed for long periods.

### Life history

The eggs are laid on larval foodstuffs, sometimes on furs and woollen fabrics and very readily on dried animal remains (especially dead insects). The eggs are often thrust into crevices of the breeding material, but even if not, they are apparently stuck to it by a secretion which resists dislodgment by shaking.

The larvae emerge from the eggs and begin to feed. They are rather squat, brown, hairy grubs, bearing three pairs of bunches of characteristic golden hairs on the posterior segments of the abdomen. When these hairs are examined under the microscope, they are found to be segmented and to bear small arrow-like heads. When the larvae are disturbed, they often curl themselves up and spread out these curious tufts of hair fanwise, giving the appearance of tiny golden, hairy balls.

Throughout life, the larvae tend to avoid the light and to burrow into their feeding material. The normal diet contains keratin and all types of keratin are suitable. However, like the clothes moths, they require additional nutrients to complete development. Some extensive investigations with *A. vorax* were made to determine the effects of the additional nutrients. (An infusion of horse dung was used, at different strengths, added to clean wool.) As the quality of the food decreased (more dilute solutions used to impregnate the wool), the larval mortality increased and the growth rate fell off rapidly. Another effect of a sparser diet on *Anthrenus* (which also occurs with other insects) is the prolongation of each stage, of the total development and an increase in the number of moults (from the minimum up to about 30).

On a very inadequate diet, death finally sets a limit to this prolonged development with numerous moults.

Well-fed larvae of *Anthrenus* are very resistant to starvation. Under rather cool conditions, larvae of *A. scrophulariae* have survived 10 months without food.

Temperature has its usual accelerating effect on the larvae, providing they have an adequate diet. One species (*A. vorax*) requires a fairly high temperature (25°C; 77°F) for pupation, and it will not complete its development unless fairly warm conditions prevail for this part of the life history.

The effects of moisture have only been roughly studied. A high relative humidity (90–100%) was found to be more favourable than a rather low one (30–40%) and development was shorter under moist conditions.

The fully grown larva measures about 4 to 5 mm in length. Pupation occurs inside the last larval skin, usually without leaving the breeding site. The newly formed adults also remain resting inside the old larval skin for a period ranging from 4 or 5 days to a month, according to the temperature.

Finally, the adults emerge and tend to seek the light, so that they usually fly to the windows and eventually escape out of doors. Mating can take place at once and the females of some species can lay eggs without taking any food. Usually, however, the adults congregate on various flowers and feed upon pollen and nectar. Thus the beetles may often be found in the garden during the summer months.

In late summer and autumn, the females tend to re-enter houses to lay their eggs. The numbers of eggs laid range from about a score to a hundred or so.

### *Life cycle*

In temperate climates there is usually only one generation per year. Eggs are laid in the summer. The larvae feed until winter when they hibernate if conditions become cold. Feeding resumes in the spring and pupation occurs in February or March. The adults appear from the end of March and occur throughout the summer.

### *Speed of development*

*A. verbasci*. E at 18°C (64°F), 31 days; at 23–24°C (73–75°F), 14 days; at 29°C (84°F), 11 days; L (room temperature New York), 222–323 days; P, 10–30 days. Total (New York; Germany), 7–14 months.

*A. vorax*. E at 18°C (64°F), 32 days; at 24–25°C (75–77°F), 16–17 days; at 30°C (86°F), 10 days; L at 20°C (77°F), 370–406 days; at 25°C (77°F), 118–135 days; at 30°C (86°F), 77–95 days; P at 25°C (77°F), 13 days; at 30°C (86°F), 9–10 days. Total at 20°C (77°F), P at 25°C (77°F), 420–450 days.

*A. scrophulariae*. P at 18–20°C (64–68°F), 18–19 days; at 25°C (77°F), 14 days; at 27°C (80°F), 10–11 days.

*A. museorum*. P at 20–22°C (68–71°F), 9–10 days. Total at 18°C (64°F), 10–11 months.

### *Attagenus*

Beetles of this species are intermediate in size between *Dermestes* and *Anthrenus*, being of the range 3.4 to 6 mm in length. The two commonest species are

oval-oblong beetles, densely coated with hairs which are mostly, or entirely, brownish black. They may be distinguished as follows:

### Adults

Whitish or yellowish spot about the middle of each elytron *A. pellio* (Fig. 42c)  
Elytra unicolorous *A. piceus* ('black carpet beetle')

### Larvae

Numerous flat, striated, broadly lanceolate scales on back of thorax and abdomen *A. pellio*

Body without flattened lanceolate scales *A. piceus* (Fig. 42f)

*Distribution.* *A. pellio*: Europe, Asia, Africa, North America. *A. piceus*: Cosmopolitan. Indigenous in Oriental region.

### Occurrence

These beetles are fairly common in warehouses and in dwelling houses, where they may breed in furs, skins and woollen fabrics (especially carpets). They are also found among stored grains and cereals, partly feeding on the remains of other grain pests. As a domestic nuisance, *A. pellio* is more prevalent in Europe and *A. piceus* in North America.

### Life history

The life history of *Attagenus* resembles that of *Anthrenus* in outline. The females enter houses in the summer months to lay their eggs on materials suitable for larval food. The larvae will feed on woollen fabrics (especially carpets), furs and other dry substances of animal origin. They are also found among dry vegetable products which they undoubtedly consume, but they may also subsist on the dead bodies of other insect pests.

The larvae, which consistently tend to avoid the light, are of the usual hairy type characteristic of the family and they have a distinctive tuft of very long hairs at the end of the body. They moult from 6 to 20 times or possibly even more under very adverse conditions. As with other pests of this type, inadequate diet, as well as low temperature, prolongs the larval period and increases the number of moults.

Pupation finally occurs inside the last larval skin and the adult rests inside for a period (of 3 to 20 days) before emerging to live an active life.

The adults tend to fly out of houses and congregate on flowers (especially *Spiraea*) where they feed on pollen and nectar and mate with each other. The life of the adult at 29°C (84°F) is about 15–25 days; at 18°C (64°F) it is about 35–40 days if mated and 60–75 days if unmated. The females lay about 50–100 eggs, averaging about 75.

### Life cycle

In temperate regions the life cycle shows considerable variation, from about 6 months to 3 years, according to diet and other unknown circumstances. A one-year cycle is probably most common. In this cycle, the adults occur from late April to

August and the eggs are laid from late May to late August. The larvae hatch in June to September and pupate in the following spring between April and June.

*Speed of development.* E at 18°C (64°F), 22 days; at 24°C (75°F), 10 days; at 30°C (86°F), 6 days. L at 25–30°C (77–86°F), 65–184 days (depends upon food rather than temperature within this range). P at 18°C (64°F), 18 days; at 24°C (75°F), 9 days; at 30°C (86°F), 5½ days.

### *Trogoderma*

*Trogoderma* beetles are rather small (2–5 mm), egg-shaped, convex beetles, covered with brownish hairs, frequently with bands or patches of paler hairs. Two species are considered in this book:

Eyes indented on the inner side

*T. versicolor*

Eyes gently rounded on inner side

*T. granarium* (Fig. 35d)

### *Occurrence*

*T. granarium* (the 'khapra beetle') is essentially a grain pest and is dealt with on p. 299.

*T. versicolor* is a well-known pest of insect collections and it is also liable to develop in woollen fabrics and furs. This beetle is also found among stored food, partly feeding on it and also devouring remains of other grain pests. Out of doors, *T. versicolor* is a common scavenger of dead insects in various situations.

### *Life history*

The eggs are laid on a variety of dry organic substances, though the larvae thrive best on animal remains. The speed of development and the number of moults vary according to the quality and quantity of the food and the temperature. As usual, sparse food induces prolonged development with numerous moults. The larvae show astonishing powers of resistance to starvation. (They have survived as long as five years without food, and at any time before death, they are able to recuperate if offered suitable food.) During starvation they moult and *decrease* in size so that they may actually reduce below their original size on hatching from the egg.

Pupation occurs inside the last larval skin, and adult life begins with a quiescent period before they emerge to live an active life. These beetles require no food or water to attain full fecundity. They tend to avoid the light for most of their life except towards the end.

The number of eggs laid by each female varies according to the diet during larval development. The usual average is about 50 to 100.

### *Life cycle*

In North America and in Russia, two generations per year have been reported.

*Speed of development.* E, 8–12 days; L, about 5 months; P, 11–17 days. Total, (under 'optimum conditions') 2 months; (usually) about 6 months.

### (d) **Importance**

The family name dermestid ('skin feeder') indicates the principal type of damage caused by this group. Great losses are incurred by the hide and fur trades by attacks

of these beetles, which are especially prone to destroy raw skins and hides, though finished garments or furnishings of wool, fur or silk are also liable to attack. In addition, the beetles may damage various stored food products. Dried materials of animal origin are mainly infested (e.g. dried or smoked fish or meat, cheese, dried milk, etc.), though some forms will also feed on cereals, cereal products and seeds.

In order to understand the destructive propensities of various dermestids, it is desirable to review their feeding preferences. Almost all the serious damage is due to the larvae. The adults of several genera (e.g. *Anthrenus* and *Trogoderma*) do not eat the larval food, but normally feed out of doors on the pollen or nectar of flowers. Other forms require little or no food in the adult stage; only the adults of *Dermestes* do more than insignificant damage to commodities, but even in this genus the larvae are much more serious pests.

Nests of birds and rodents are two important reservoirs likely to provide sources of these domestic pests. A considerable number of species has been recorded from these situations, where the larvae apparently feed upon cast feathers or hairs, fragments of food and dead insects. The larvae have even been found attacking weakly nestlings and feeding on the wings.

Various dermestids have the habit of breeding near spiders' webs and feeding on captured insects or even on the eggs or young of the spiders. Others live in the nests of wasps and bees, where again they feed on dead or dying insects and also, to some extent, on honey or pollen.

The original natural diet of the dermestid larvae appears to have been dry proteinaceous materials of animal origin. Most members of the group are unable to complete development unless they obtain some food of this type; but others have adapted themselves to a vegetarian diet and can develop successfully on it, though they normally prefer animal matter. Only one species (*Trogoderma granarium*) habitually breeds in vegetable matter (see p. 299).

Among the forms restricted to animal diet, there are some which usually or always confine their feeding to more or less raw products such as dried or smoked meat skins and hides, museum specimens, silkworm eggs and pupae. These include all species of *Dermestes*, some *Attagenus* and some *Anthrenus*. Other forms (*Attagenus piceus*, *Anthrenus vorax*, *A. verbasci* and *A. scrophulariae*), as well as attacking these raw products, are also serious pests of highly processed commodities containing animal matter, such as carpets, woollen clothes, furs, leather or silk. To some extent this ability to develop on processed animal products is due to a capacity for feeding on food with a very low water content. (Whereas fish meal might be expected to contain 45% moisture, a woollen fabric under the same conditions would contain only 11-12%.) Apart from this, the nutritive value of sterols present in the raw products (and absent from scoured wool) may be essential for some species.

In addition to the hides, skins and other animal products which dermestid larvae attack for food, a very considerable amount of damage is caused by a habit of the fully grown larvae. After completing larval development they have a strong tendency to excavate cavities in quite hard, inedible materials to form shelters in which to pupate. The woodwork of boxes, buildings, ships and barges may be attacked and also many other products stored in the vicinity of infested materials. Even leather

overs of electrical cables have been badly damaged by dermestid larvae with resulting short-circuiting.

Finally, two unusual but quite troublesome nuisances due to dermestid larvae may be cited; damage to insect collections and to silkworm pupae. Dead insects form a natural food of many dermestid larvae and it is therefore easy to see why they are about the most serious pest of insect (and other) specimens in museums. The species mainly responsible are *Anthrenus verbasci*, *A. museorum*, *A. scrophulariae* and *Trogoderma versicolor*.

In the silkworm industry, dermestids cause trouble by devouring the helpless pupae and eggs. Cocoons which are damaged in the attack on pupae are completely spoiled for silk production.

#### *Dermestids and disease*

Dermestids play only a very minor role in disease transmission. There have been records of mechanical transmission of anthrax germs by beetles from infected carcasses, but this must be a rare occurrence.

The hairs dislodged from dermestid larvae have been observed to cause skin irritation and conjunctivitis to workmen unloading a badly infested cargo of skins.

#### *Uses of dermestids*

One ingenious use of these insects is to allow them to clean up vertebrate skeletons for exhibition purposes. They are said to remove all unwanted tissues from even the most delicate structures.

### (e) **Control of dermestid beetles**<sup>(19)</sup>

Two kinds of infestation must be considered. In hide and skin warehouses, in bone-wards and other large accumulations of animal matter of this type, there may be heavy and obvious infestations. Infestations in dwelling houses, on the other hand, are usually small, but they may be annoying and the breeding sites are often hard to trace.

#### (i) *Warehouse infestations*

When large quantities of hides or skins are infested (usually with *Dermestes* sp.) it may be necessary to dip them in an arsenical solution. A 2½% solution of sodium arsenite is effective and the arsenic does not affect the leather in any stage of its manufacture. The men carrying out the treatment must wear protective rubber gloves.

Alternatively, under suitable conditions (reasonably gas-tight buildings) hydrogen cyanide fumigation may be employed. The dermestid beetles are rather resistant to fumigants so that a good concentration of the gas should be ensured. Fumigants other than hydrogen cyanide should not be used unless there is good evidence of their effectiveness against these pests.

As a protective measure, skins and raw hides are usually baled up with layers of flake naphthalene before despatch on ships or other long journeys.

(ii) *Domestic infestations*

Very often the site of breeding in a dwelling house is obscure and the presence of the insects becomes noticed by repeated appearance of adults or, sometimes, of wandering larvae. The first essential is to trace the focus of the infestation. When the pest has been identified, some indication of the possible breeding ground will be gathered from the food preferences of the various species, as already described (See also the section on the importance of the group.) The larder should be examined for neglected pieces of dried meat or other dry protein. An alternative source of dried animal matter may be a dead rodent under the floor or a dead bird in the attic. Neglected woollen garments or furnishings (especially carpets) should be examined, particularly any which have been allowed to become dirty. Woollen felt used in lagging pipes or for other insulating purposes should not be forgotten. Finally, it should be remembered that dermestids sometimes breed in bird nests and that they may be entering the house from such places under the eaves.

When the breeding focus has been traced, it should be thoroughly extirpated, if possible, by burning the infested material. If an article of value is attacked, it may be necessary to use spray insecticides; these should be applied very thoroughly to kill all the larvae.

For protecting woollen fabrics or furs from possible attacks of dermestid beetles the same measures may be employed as against the clothes moths (see pp. 359-362).

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# 14 · Wood-boring beetles

## I · LIABILITY OF WOOD TO ATTACK BY BEETLES

In order to understand the potentialities of different beetles for damaging different kinds of woodwork, it is necessary to consider some of the factors which render wood liable to attack.

### (a) Water content

Wood which is prepared for use as structural timber or furniture is obviously much drier than the wood of living trees or even the wood of logs lying on the forest floor. It is, indeed, a very dry foodstuff; and this fact probably excludes many of those wood-feeding insects which attack trees in the forest. The domestic timber pests (like many pests of stored foodstuff or fabrics) are well adapted to a dry diet. The wood which they swallow needs to be soaked in digestive juices to be assimilated; but all possible water is extracted by the hind part of the gut, so that they pass dry and powdery faeces ('frass').

As wood dries from fresh green timber it approaches an optimum for the domestic wood beetles and further drying renders it unsuitable as food. Thus the *Lyctus* or powder-post beetles will not attack newly felled timber which has a water content of 30% or over. As it dries it becomes more and more liable to damage, the optimum being about 12-15%. Below this level, the lack of moisture becomes deleterious and prevents attack below 8% water content.<sup>(26)</sup>

### (b) Chemical constituents of wood<sup>(23)</sup>

Apart from its lack of moisture, dry wood does not appear to be very promising as a diet. Until recent years there was very little knowledge about the nutrition of the wood-boring insects. The main constituents of wood are: Cellulose, 40-62% dry weight; Lignin, 18-38% dry weight; Hemicelluloses, 8-37% dry weight; Starch, up to 6% dry weight; Sugar, up to 6% dry weight; Proteins, 1-2% dry weight.

It has been shown that different wood-feeding insects consume different constituents. The lignin is only attacked to a minor extent, but several groups of insects are able to digest cellulose. Some (Anobiidae) can do this directly, by the action of their own digestive enzymes. Others, like certain termites, rely upon the preliminary digestion of the cellulose by micro-organisms (protozoa) in their intestines.

One important group, the Lyctidae, cannot digest lignin, cellulose or hemicellulose. They depend entirely upon starch and small amounts of sugars in the wood. *Lyctus* beetles are therefore only able to develop in wood which contains starch.

It is probable that both the anobiids and the lyctids assimilate small quantities of protein from the wood cells; but their nitrogen requirements are not great.

**(c) Condition of the wood<sup>(3, 4)</sup>**

It has been known for some time that structural timber or portions of it which have become decayed by continual exposure to rather damp conditions, is especially liable to attack by the death-watch beetle. Laboratory experiments have shown that this beetle has difficulty in establishing itself in sound timber and that its development in sound, or nearly sound, wood is very slow indeed. The length of the larval period and the larval mortality are both decreased to a large extent if the wood has been subjected to fungal attack. The type of fungus is not particularly important since the most important benefit of decay to the insect is the softening of the wood, allowing more rapid larval penetration. The fungi which were in fact investigated were brown and white rots (basidiomycetes); these attack both cellulose and lignin and other constituents equally, so that their only overall chemical effect is a slight concentration of nitrogen, which may be somewhat beneficial. More recently, similar investigations with furniture beetle revealed the same facilitation of attack in wood attacked by these fungi and also by soft rots.<sup>(5, 6)</sup> It is also noteworthy that wood-boring weevils and the wharf borer are only prone to infest wood which has been attacked by fungi.

**(d) Plywood**

The cheaper grades of plywood of the birch-alderwood type, made up with blood-casein glue, are very frequently attacked, and it has been shown that these glues accelerate growth of woodworm. However, plywood bonded with synthetic glue, such as urea-formaldehyde, seems to be immune to furniture beetles, though it may be attacked by powder-post beetles.

**II. THE DOMESTIC WOOD-BORING BEETLES<sup>(7, 19)</sup>****(a) Distinctive characters**

The principal wood-eating insects are the termites, various members of certain families of beetles and the wood-wasps. Of these, the termites fortunately do not occur in Britain; and the wood-wasps and many of the beetles are pests of the forest and do not attack wood in human dwellings. Certain beetle pests of the forest may produce holes in wood which may be subsequently confused with those caused by domestic timber pests. These are the so-called pin-hole or shot-hole borers, belonging to the families Platypodidae or Scolytidae. They attack trunks and branches of living trees or, in some cases, freshly felled trees. When the wood dries sufficiently for use as structural timber or furniture, the beetle larvae die, so that they cannot be responsible for infestations in houses. Their burrows, however, remain and may be visible as holes in cut timber or plywood. These tunnels are round, ranging between 0.5 and 3 mm in diameter (hence 'pin-hole' or 'shot-hole'). It is necessary to distinguish these harmless relics from the signs of attack by beetles which can damage seasoned wood. This is easily done by two criteria. (1) The wood surrounding the galleries of the pin-hole or shot-hole borers are always stained, usually a purplish brown. This staining is a residue of the fungi which the beetles cultivate in them for food, for which reason they are sometimes called 'Ambrosia

beetles'. (2) The galleries are empty. In contrast, the galleries of domestic wood boring beetles are unstained and are usually full of frass (powdery faeces).

The beetles which do damage furniture or structural timber are forms which, in nature, breed in dead branches of trees or old logs. These beetles, together with certain fungi, perform a useful function in nature by breaking down the waste lumber of the forest. They become troublesome to man when they attack the particular timber which he uses for his own purposes.

#### *Recognition of genera and species*

The beetles which damage domestic woodwork in Britain belong to five families.

Anobiidae	<i>Anobium punctatum</i> (common furniture beetle)
	<i>Xestobium rufo-villosum</i> (death-watch beetle)
	<i>Ernobius mollis</i>
	<i>Ptilinus pectinicornis</i>
Lyctidae	<i>Lyctus</i> spp. (powder-post beetles)
Cerambycidae	<i>Hylotrupes bajulus</i> (house longhorn beetle)
Curculionidae	<i>Euophryum confine</i>
	<i>Pentarthrum huttoni</i>
Oedemeridae	<i>Nacerdes melanura</i> (wharf borer)

The adults of the more important genera (*Anobium*, *Xestobium*, *Lyctus*, *Hylotrupes*, *Euophryum*, *Pentarthrum*) may be distinguished by the main beetle key on page 454. The two other anobiids, which are rather uncommon, resemble *Anobium punctatum* but can be distinguished as follows.

*Ptilinus pectinicornis* is slightly larger (3–6 mm) and more cylindrical. The males are easily recognized by their branched antennae (Fig. 43c); those of the females are merely toothed like a saw.

*Ernobius mollis* is also larger (up to 6 mm) and when freshly emerged is covered with golden hairs (though these tend to become rubbed off). The wing cases are less horny than those of *Anobium*.

The more important larvae may be identified by another key (p. 458).

The two common species of *Lyctus* are *L. brunneus*, an American species, which has now become much more common than the native British species *L. linearis*. The adults may be distinguished as follows:

Hairs on elytra in definite rows; pro-thorax with nearly parallel sides	<i>linearis</i>
Hairs on elytra not clearly arranged in rows; pro-thorax wider in front with sides slightly concave	<i>brunneus</i>

#### *Signs of attack*

Some indication of the type of beetle which has been responsible for timber damage can be gained by examining the frass (larvae faeces) and exit holes. See Table 15.

#### (b) Life history

The furniture beetle (*Anobium punctatum*) (Fig. 43a & b)

The females choose suitable places to deposit their eggs, the condition of the wood surface being apparently more important than the kind of timber. They are able

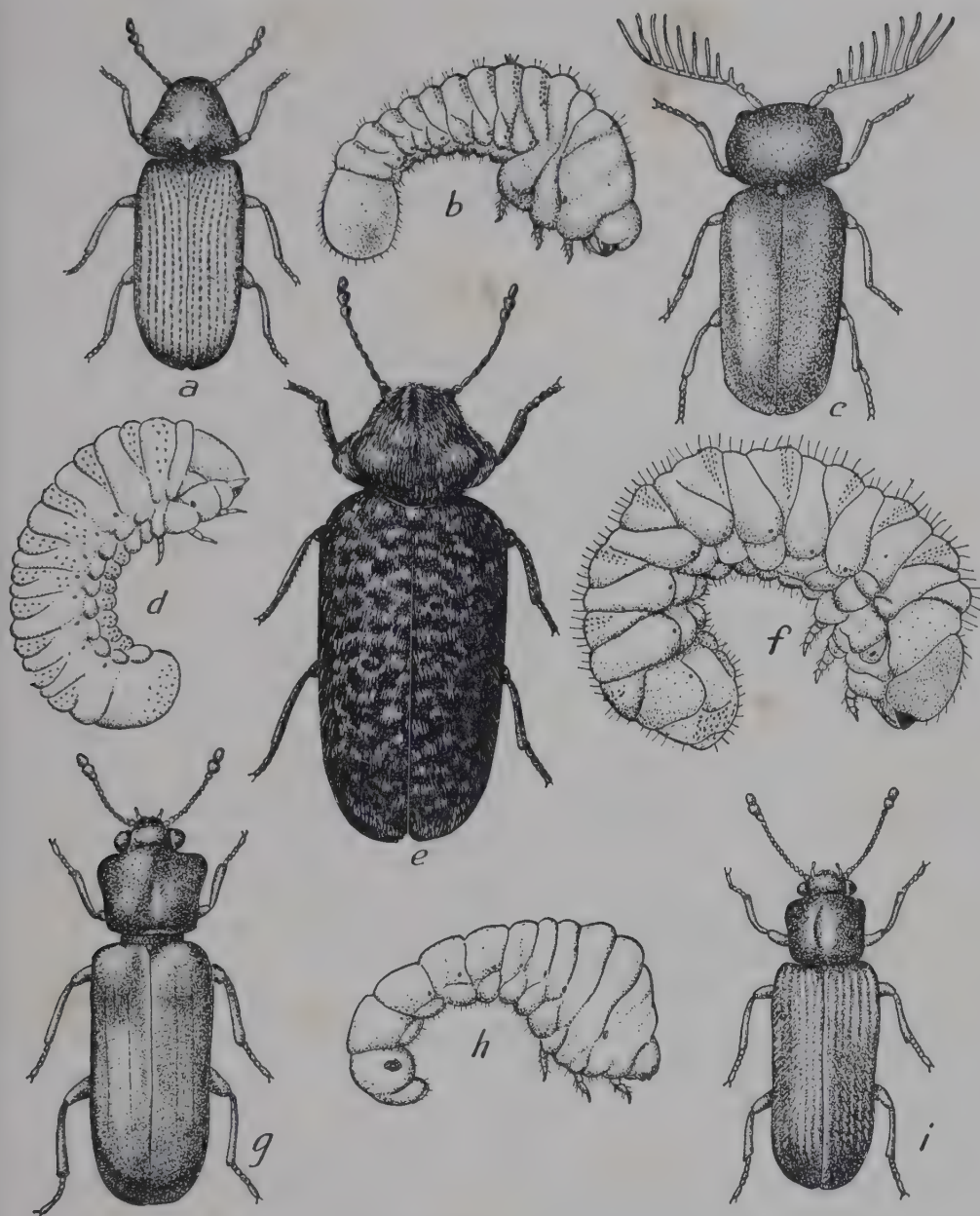


FIG. 43. Wood-boring beetles and their larvae. (a) adult and (b) larva of *Anobium punctatum*; (c) adult and (d) larva of *Ptilinus pectinicornis*; (e) adult and (f) larva of *Xestobium rufovillosum*; (g) adult and (h) larva of *Lyctus brunneus*; (i) adult of *Lyctus linearis*. (d) after Munro (*Proc. R. Phys. Soc. Edin.* **19**, 220); (e) original; (f) after Parkin (*Bull. ent. Res.* **24**, 33). Remainder after Gahan and Laing (*B.M. (Nat. Hist.) Econ. Series No. 11*). All  $\times 7\frac{1}{2}$ .

to extend their ovipositors telescopically, to a length nearly half that of the whole body, and the tips of these organs are used to probe the surface to discover small holes and crevices into which the eggs can be wedged as they are laid. In addition an adhesive secretion on the surface tends to bind them to the wood.

The eggs are oval or lemon-shaped, white in colour and about 0.4 mm long. Under the microscope each egg shows a fine honeycomb-like sculpturing which extends for one-third of its length from one end, the remainder being smooth.

The larvae emerge from the egg shell surface in contact with the wood and begin to tunnel into the timber with the capsule still in place.<sup>(22)</sup> The first-stage larvae are very small and straight; they acquire the characteristic curled shape of this type of larvae as they grow older. The appearance of the older grubs is shown in Fig. 43*b*. It will be seen that they bear rows of small brown spines ('spinules') on the more prominent ridges of some of the dorsal segments; these probably assist in gripping the sides of the burrow. The larvae possess powerful mandibles with which they dig into the wood. Part of the wood is swallowed, digested and extruded as faeces in the form of small oval pellets. The mixture of wood fragments and faeces which fills up the burrow as the larvae move forward, is known as 'frass'.

The burrows in the wood usually move along in the direction of grain. The larvae gradually grow in size and increase from a body weight of 0.005 mgm on hatching to about 13 mgm when mature.<sup>(2)</sup> The fully grown larva reaches a length of about 5 mm ( $\frac{1}{5}$  inch). As the larva grows, the size of the burrow naturally increases, till it reaches a diameter of about 2 mm ( $\frac{1}{12}$  inch). Very badly attacked wood may contain 2 or 3 larva per cubic centimetre.

When it is fully grown, the larva prepares to pupate. The course of the burrow is directed towards the surface of the wood and, just below the surface, a slightly enlarged chamber is excavated. In this cell pupation takes place. The pupa is of the usual beetle type with the adult limbs lying close to the body but not adhering to it.

When the adult beetle is ready to emerge, it waits until its jaws and body have hardened, and then bites an emergence hole through the thin layer separating it from the free air. The appearance of these beetles is shown in Fig. 43*a*) they are from 2.5 to 5.0 mm long and of a reddish-brown colour, modified somewhat by a covering of short yellow-grey hairs. The beetles may be seen crawling about on walls, ceilings or windows in the summer months. On warm days, they fly readily and thus may spread infestation to new sites; in flight they may be mistaken for small flies. Like many other insects, they have the habit of 'shamming death' when suddenly disturbed; the appendages are drawn close to the body and they remain motionless for some time.

In Germany *Anobium* is given the name 'Totenuhr' (death watch) which is reserved for *Xestobium* in Britain, because of the tapping noise which it is said to produce. There seem to be no British records of the production of audible sound by *Anobium*.

The sexes are about equal in numbers and pairing takes place freely on warm days. The females may mate several times in the course of their lives. A day or so after copulation the females begin egg-laying without requiring any food in the meantime. At 20–22°C (68–71°F) and 80–90% R.H., the adults were mostly observed to live for 20 days and a few for over 30 days.<sup>(1)</sup>

### *Natural enemies*

The larvae of *Anobium* are preyed upon by the larvae of certain other beetles of the family Cleridae, which seek them out in their burrows. *Anobium* larvae are also attacked by the mite *Pyemotes* (see p. 333) and by various tiny parasitic wasps of the family Braconidae.

*Life cycle*

The duration of the life cycle extends apparently for about 3 years under normal room conditions. Wood may be found containing larvae of all sizes corresponding to different ages; those of 7 mgm and over may be presumed to be in their third year.<sup>(1)</sup>

The adult beetles emerge, mate and lay their eggs throughout the summer (June–August).

*Speed of development*

E at 15°C (59°F), 59 days; at 20°C (68°F), 19–20 days; at 28°C (82°F), 15–16 days; L, (?) 3 years; P at 20°C (68°F), 14 days; at 28°C (82°F), 10 days.

Death-watch beetle (*Xestobium rufo-villosum*) (Fig. 43e & f)<sup>(8, 9)</sup>

Egg-laying seems to occur mainly in the daytime. The pregnant females walk slowly over woodwork, exploring possible egg sites, first with their antennae and then by probing with their ovipositors. Into suitable holes or crevices the ovipositor is extended and an egg laid. Sometimes groups of 2 or 3 up to more than 100 may be found in favourable sites. There is no evidence that the females are able to choose the decayed portions of wood which are most favourable for larval development.

The eggs are lemon-shaped, white in colour and about 0.6–0.7 mm long.

The young larvae emerge and they may crawl over the wood to choose a site for boring. Larval life is spent tunnelling through wood. The burrowing is able to progress much more freely in wood which has been weakened by fungal decay and the larvae thrive better in such wood.

As with *Anobium*, pupal cells are formed near to the surface of the timber. After completing pupation, the newly formed adults remain inside the pupal cells until the following spring before biting their way out. The beetles resemble *Anobium* in shape, but they are larger (7 or 8 mm long) and the elytra are mottled by patches of short yellowish-grey hairs.

The activity of the adult beetles depends upon the temperature. In natural infestations out of doors, the beetles are usually found resting under bark except in hot weather. On warm sunny days, or inside warm buildings, they tend to walk about over the surface of the wood. The beetles rarely, if ever, fly voluntarily though they will flutter their wings sometimes if launched into the air. The frequent infestation of wooden beams in the roof suggests that they may sometimes fly unobserved. However, they certainly depend a great deal on walking and may very often be carried into an uninfested building on a piece of infested timber. Intermittently they produce the characteristic tapping sound which is responsible for the common name of death-watch beetle. This is a series of 7 or 8 clicks in quick succession, caused by the beetle rapping its head against the woodwork. The sound is, no doubt, somewhat eerie and foreboding in a large, quiet, old oak-panelled or oak-timbered building. Both sexes will emit the noise; it is apparently a sexual call and can be elicited in a captured specimen by similar noises made

artificially. The beetles mate quite freely at a temperature of 20°C, the male mounting on the back of the female and remaining in copulation for about  $\frac{1}{2}$ –1 $\frac{3}{4}$  hours.

### *Life cycle*

The total life cycle depends not only on the temperature but on the suitability of the infested timber. Experiments at the Forest Products Research Laboratory<sup>(9)</sup> indicate a life cycle of 1 to 6 years indoors at a temperature of 22–25°C (71–77°F). Outdoors in a place sheltered from sun and rain, the life cycle extended for 3 to 6 years.

### *Speed of development*

E at 15°C (59°F), 40–50 days; at 20°C (68°F), 20–24 days; at 25°C (77°F), 12–15 days; L, 1 to 10 years; P at 18°C (64°F), 20–28 days; at 23°C (73°F), 18 days.

Powder-post beetle (*Lyctus* spp.<sup>(24, 25, 26)</sup>) (Fig. 43g, h, i)

Oviposition occurs mainly at the period of maximum activity which is at dusk. As already mentioned, the larvae of *Lyctus* depend for their nourishment on starch present in the wood. The egg-laying females 'taste' the wood before depositing their eggs and are thus able to distinguish suitable breeding material for their progeny. On a suitable exposed piece of wood, the females seek the transverse or longitudinal cut surfaces and lay their eggs in the pores; that is, in the exposed openings of the wood vessels. The ovipositor is inserted into the mouth of the pore and one or more eggs inserted, so that they may lie some distance from the surface.

The eggs are long and narrow, with a stalk-like prolongation at the top. If they are thrust into rather narrow vessels, they may be distorted by pressure so that they become even longer and narrower than usual.

The mature first-stage larvae begin by feeding on the residual yoke mass in the egg and eat their way forward and out of the shell. Then they may consume a few particles of the walls or contents of the wood vessel before settling down to moult. The second-stage larvae begin to bore into the surrounding wood (and often turn through one or two right angles to avoid reaching the surface of the wood).

The larvae gnaw their way through the wood swallowing a portion of it and filling their burrows up with 'frass' consisting of powdery faeces and wood fragments. There are no salivary glands to digest the swallowed wood, but the digestive juices (enzymes capable of hydrolysing starch, sugars and protein) are secreted by the midgut. The skeletal substance of the wood passes through the gut unchanged, the nourishment being derived from the cell contents. To a large extent the larvae rely on starch and they cannot develop in starch-free wood. For this reason they are confined to the sapwood; and where (as often happens) the starch is irregular in distribution, the larval attack will often be concentrated in patches or bands of high starch content.

The larvae gradually grow to a length of about 6 mm ( $\frac{1}{4}$  inch) in length. They resemble those of *Anobium* in general appearance but differ in the absence of spinules and the enlarged eighth abdominal spiracle which shows up very distinctly as a brown spot.

When they are mature, the larvae direct their burrows towards the exterior and pupate just below the surface. After the pupal period, the adults remain inside the pupal chamber for 3 or 4 days before biting an exit hole and emerging. The adults are reddish-brown to dark brown in colour and vary considerably in size (3 to 6 mm in length).

The activity and reaction of the adults are closely related to temperature and light conditions prevailing. They are very active at temperatures above 20°C (68°F) when they run about on the surface of the wood. The activity is, however, mainly in the evening; during the day they often crawl into crevices between boards or hide in old exit holes. But at dusk they become active and frequently fly about. Copulation can take place immediately after emergence; it is most frequently observed at dusk. Both sexes usually live about 3 to 6 weeks, the longest observed life in the laboratory being 68 days.<sup>(24)</sup>

### *Life cycle*

The normal life cycle in Britain, under favourable conditions, is an annual one; but in wood with a low starch content, this may be extended to two years. The adults emerge, mate and reproduce in the spring and summer and the next generation larvae overwinter as half-grown or nearly mature larvae.

### *Speed of development*

(*L. bruneus*) E at 20–23°C (68–73°F), 8–8½ days; P, about 3 weeks. Total at 23°C (73°F) in sapwood of English oak, 6–12 months.

### House Longhorn beetle (*Hylotrupes bajulus*<sup>(2, 27)</sup>) (Fig. 44a)

The females oviposit several times (1–7 times) and lay a total of about 100 eggs, though as many as 500 have been recorded. They are attracted to soft woods by the odour of their characteristic resins and lay eggs in small crevices.

The eggs are spindle-shaped, about 2 mm long.

The larva is a straight-bodied fleshy white grub, divided by deep transverse folds into rings or segments. The head is sunk into the prothorax, so that only the dark brown jaws are visible. They burrow into the wood forming a tunnel which becomes crammed full of powdery frass. If the walls of the tunnel are carefully examined, the bite marks of the larvae can be observed, even with the naked eye. These marks, said to resemble ripples in the sand left by the tide, are apparently characteristic of the pest.<sup>(19)</sup> The larval tunnels are often parallel to the surface and separated by a thin layer, which may bulge outward, like a blister.

The larvae (Fig. 44a) grow to a length of about 30 mm and then pupate, near the surface as usual.

The adults (10–20 mm) bite their way out of the wood, leaving their characteristically large emergence holes. Since relatively few larvae can destroy a large amount of wood, the emergence holes are relatively rare. The adults do not live long (males 1–2 weeks, females 2–3 weeks). In the laboratory they do not feed, but probably do so in the field.

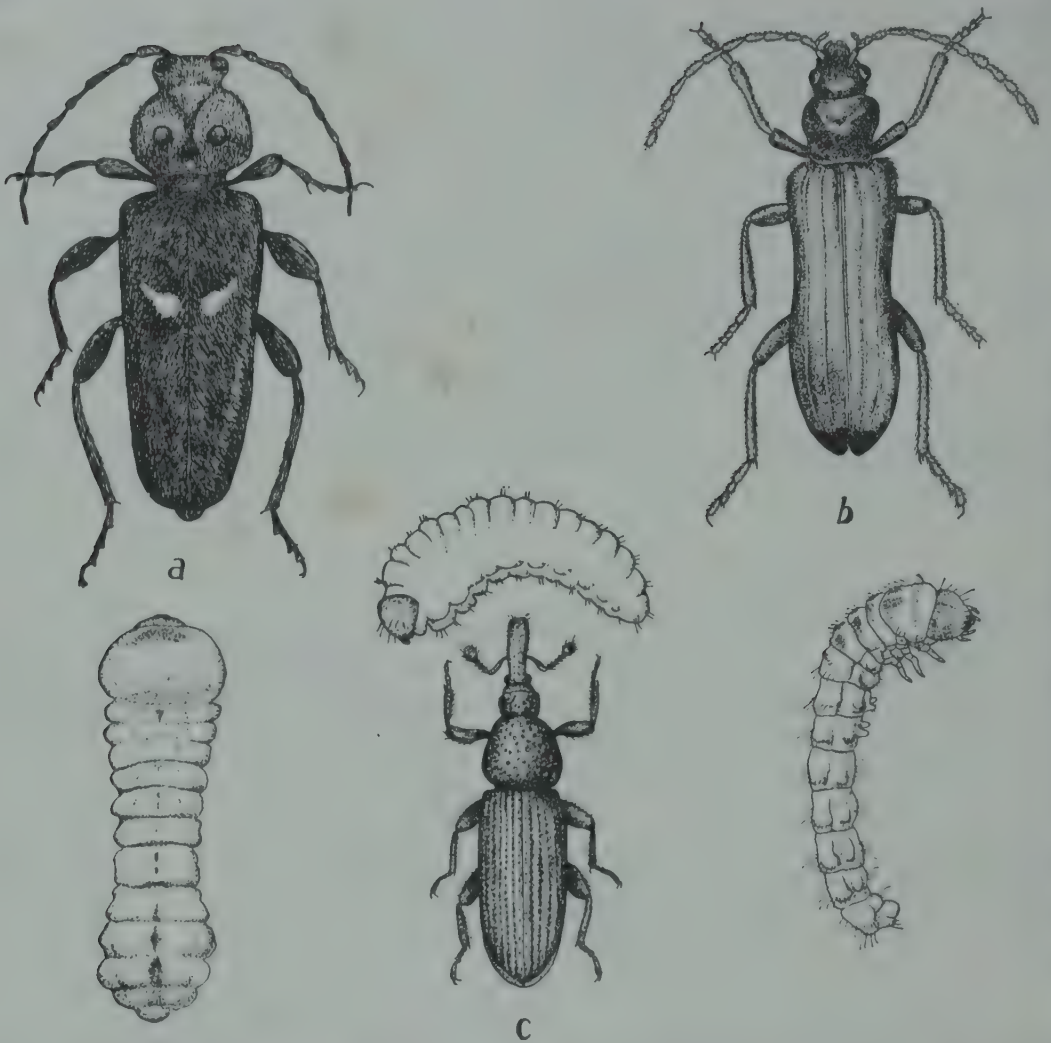


FIG. 44. Further wood-boring beetles and their larvae. (a) *Hylotrupes bajulus*; (b) *Nacerdes melanura*; (c) *Euophryum confine*. Magnifications: (a)  $\times 1.5$ ; (b)  $\times 5$ ; (c)  $\times 10$ . (a) after Forest Products Research Laboratory Leaflet No. 14. (b) (c) after Britten, E. B. (1961) *Domestic wood-boring beetles*, B.M. (Nat. Hist.) Econ. Ser. No. 11a.

#### Life cycle

In Europe, the life cycle ranges from 3 to 11 years, being affected by the nature of the timber as well as environmental conditions. The adults emerge during the summer months.

#### Speed of development

E at  $16.6^{\circ}\text{C}$  ( $62^{\circ}\text{F}$ ), 48 days; at  $31^{\circ}\text{C}$  ( $87^{\circ}\text{F}$ ), 6 days. L & P (in South Africa), 1.75–5 (av. 3) years.

#### *Euophryum confine*<sup>(21)</sup> (Fig. 44c)

Little is known of the life history. The larvae tunnel in the wood forming a series or inter-communicating, more or less parallel galleries, thinly divided from each other and partly choked with frass. Many galleries are close to the surface and only covered by a thin layer of wood.

*Life cycle*

Adult beetles (3–5 mm) have been found from March to December, which seems to indicate that there may be two overlapping generations in a year.

*Pentarthrum huttoni*<sup>(15)</sup>

The life cycle has been studied at 25°C (77°F) and 95–100% R.H. About 4 days after mating, the female lays her eggs, singly in holes excavated by the mandibles or in crevices in the wood; the holes are then sealed with glue exuded by the ovipositor.

The larvae, which are legless, tunnel in the wood, forming burrows parallel to the surface. Pupation is in a cell which becomes lined with fungal hyphae. Adults emerge at tunnels at an angle of 45° to the surface.

*Speed of development.* E, 16 days; L, 6–8 months; P, 16 days.

Wharf borer (*Narcerdes melanura*<sup>(19)</sup>) (Fig. 44b)

The life history has not been carefully studied. The larvae tunnel mainly in rotten wood, though they may penetrate for an inch or so into sound wood. Water-sodden wood is chiefly attacked, especially wharf piles a foot or so above water level, or timber sunk in the ground. The pest is practically confined to wood infested with fungus, either dry rot (*Merulius lachrymans*) or one of the other fungi which attack wet wood, such as *Coniophora cerebella*.

The adults (6–12 mm) sometimes emerge in large numbers, especially in early summer, and invade dwellings and office buildings.

(c) **Importance**<sup>(7, 20)</sup>

Nearly all the 17 million private dwellings in Britain are of partly timber-framed construction. Part of the wood is structural, as in walls, floors and roof; part is in fittings, such as doors, window frames, skirtings and cupboards. Over 90% of the timber used in building is imported from North America or Europe. A very high proportion derives from *Pinus sylvestris* (Scots pine, Baltic deal, European redwood). Of secondary importance is *Picea abies* (Norway spruce, European whitewood) and, more recently, *Tsuga heterophylla* (western hemlock). Various other softwoods have also been used.

During the period 1960–3, a wide survey of timber damage was conducted by a company concerned with remedial treatment. Nearly 74,000 buildings were inspected, including all types; but largely (85%) private dwellings were involved. Roughly half of these were built before 1914 and about 40% between the wars. The results were of considerable interest. They revealed that by far the biggest wood pest was *Anobium punctatum*, causing about 75% of the infestation. *Xestobium rufovillosum* and the wood-boring weevils each contributed 4 to 5% of the cases. Surprisingly, *Lyctus* spp. comprised less than 1% of the survey. *Hylotrupes bajulus* occurred to 0.3% and miscellaneous pests were just over 2%.

The various species have rather different spheres of activity, as follows.

(i) *Anobium punctatum*<sup>(10)</sup>

*Anobium* breeds out of doors in dead or dying parts of trees and in fence and gate posts. Inside buildings, the beetle may breed in most forms of wooden furniture (including plywood and wickerwork) as well as in flooring, rafters and other structural timber. The presence of emergence holes spoils the appearance of the woodwork and the damage caused by the larvae may seriously weaken articles of furniture. In large wooden beams, however, *Anobium* does not usually penetrate sufficiently to endanger their mechanical strength. Almost any type of wood, whether from a deciduous or coniferous tree, is liable to attack; but softwoods are more usually damaged. Attack is mainly confined to sapwood (except in timber where the heartwood is not clearly distinct, such as beech, birch and spruce). Accordingly, floorboards with a high proportion of sapwood may be seriously weakened. Very old wood is less frequently infested than wood only a few years old.

Optimum conditions for development of *Anobium* are a temperature of 22–23°C (72–73°F) and a relative humidity of 80–90%. Temperatures above 28°C (82°F) and relative humidities below 40% prevent development; infestations do not flourish in very warm dry rooms, such as those in centrally heated buildings. On the other hand, the beetle can develop satisfactorily, though slowly, in unheated places such as cellars and store rooms.

(ii) *Xestobium rufo-villosum*<sup>(12)</sup>

The natural habitat of this beetle is in decayed or dying trunks or large branches of hardwoods, chiefly oak and willow; it has also been found in other hardwoods, and once or twice in conifers. As a pest in buildings, *Xestobium* is most troublesome for its attacks on structural timbers, which may actually endanger the stability of timber-framed buildings. Large pieces of furniture or fittings, such as church pews and screens or oak panelling, are also liable to attack. The beetle is essentially a pest of old seasoned wood and it has seriously damaged the roofing timbers of many old and historically important buildings.

The wood most frequently infested is oak, but other hardwoods may be involved and, occasionally, pinewood.

(iii) *Lyctus* spp.<sup>(11)</sup>

In complete contrast to *Xestobium*, the *Lyctus* beetles are mainly injurious to new or recently prepared timber. Planks and boards or partly manufactured articles are very liable to become infested while being stored in sheds by the timber merchant or manufacturer. Very often the infestation is not discovered until the wood has been made into furniture or employed for panelling, flooring or other structural uses. Complaints are made and the suppliers have to replace the damaged wood and moreover suffer from loss of reputation.

*Lyctus* is fortunately more restricted in the type of timber which it will infest. It will only breed in the starch-containing sapwood of deciduous trees. Furthermore, it has the habit of laying eggs in the pores of the wood (as described in the life history) and certain kinds of wood with very narrow pores are not infested (e.g.

horse chestnut). Others (cherry) have rather narrow pores which only just permit attack, and these are not very often infested. In spite of these restrictions, a very large number of important timbers are susceptible to this pest, including oak, walnut, ash, hickory, sycamore, sweet chestnut, elm and African mahogany; also imported tropical hardwoods like agba and obeche.

(iv) *Hylotrupes bajulus*<sup>(13, 28)</sup>

Longhorn beetles (family Cerambycidae) are essentially forest insects, which breed in the bark and wood of trees and logs. *H. bajulus*, however, is exceptional, since it can breed in seasoned wood (though it will develop even more quickly in recently felled timber). It attacks the sapwood of softwoods only.

During the present century, the status of the beetle in Europe has changed from that of a rather uncommon insect to a widespread pest. It has been introduced into North and South America and also South Africa, where it is a severe nuisance. Though long resident in Britain, it has only become a pest in the past 25 years. Though there are records throughout England it is only serious in the south, especially in Surrey. Damage in houses is usually found in structural timbers in the roof space; but doors, window frames, etc., may be attacked. It has been recorded breeding out of doors (in tree-stumps and telegraph posts) but this is not very common. Infestations may be spread by adults flying from house to house or by movement of infested timber.

(v) *Euophryum confine* and *Pentarthrum huttoni*<sup>(21)</sup>

Both these weevils attack only wood which has been (or is being) attacked by fungi; for example, *Coniophora cerebella*; one of the less serious dry rots. As a rule, then, they are most liable to occur in wood which has become damp; near leaking pipes in the vicinity of sinks, lavatories and bathrooms. They also occur in damp situations in breweries, wine vaults and beer cellars. *Euophryum confine* has been introduced into this country from New Zealand (where, apparently, it is not a pest). The first record in Britain dates from 1937, and subsequently it has been found breeding out of doors in south-east England. A number of infestations have been reported in houses in the London area.

(vi) *Ptilinus pectenicornis*

This beetle is not very often responsible for damage to domestic woodwork, being more restricted in its choice of wood. Generally speaking only hardwoods are attacked, most commonly beech, maple and sycamore.

(vii) *Ernobius mollis*<sup>(14)</sup>

The eggs of *E. mollis* are laid only on softwoods which retain the bark, and the borings are superficial. Thus it is not a serious pest and its main importance is a possible confusion with *Anobium punctatum*. Since it only attacks wood with some bark attached, it is more likely to be encountered in barns and outbuildings rather than in dwellings.

(viii) *Nacerdes melanura*<sup>(19)</sup>

This beetle is thought to be introduced from the Great Lakes region of North America. In England it has become quite common in wharves of many estuaries in the south, from the Thames round the south coast to Cornwall. It occurs not only in piling and timber supporting the river bank, but also in wooden barges. It has also been found in sodden wood largely buried in the ground and also in badly maintained houses (e.g. in leaking lavatories). On one occasion, however, it was found in a London church, 35 feet above ground.

### III · CONTROL MEASURES

#### (a) Detection of infestations

The most obvious sign of attack by wood-boring beetles are the exit holes made by the emerging adults. It is sometimes possible to distinguish emergence holes which have been recently made. Their outline is sharp and the wood within fresh and bright; dull and weathered holes are probably relics of an earlier attack. The presence of the holes proves that a piece of timber has, at some time, been infested; it is less easy to determine whether living grubs are still present. One method is to place some clean paper below the suspected wood for a day or so. If an extensive infestation is present, the activity of the grubs is liable to dislodge frass from the ramifying galleries and some of this tends to be thrown out of the exit holes on to the ground below. Frass may also be thrown out by the activity of the predatory enemies of the wood-boring beetle larvae.

During the summer months the actual beetles may be found. Adults of *Anobium* are often seen crawling on walls, ceiling or windows; or they may be seen in flight. The death-watch beetles are less active and often fall from an infested ceiling to the floor below. Since they do not wander far, their numbers and distribution may give a useful indication of the extent of activity above. Their absence from the floor, however, does not mean that the timber above is free from attack.

#### (b) Preventive measures

##### (i) *Anobiidae*

Attacks of *Anobium* in furniture are less likely if the wood is kept in a warm well-ventilated room. Structural timber which is kept in good condition and free from decay, is not liable to damage by *Xestobium*. Therefore, especial care in house construction should be taken to prevent damp conditions through leakage and bad ventilation. Some sites very liable to attack are: wall-plates, wall-posts, the feet of the principal rafters and hammer beams and timbers near the ridge.

Care should be taken not to introduce beetle larvae in timber used for repairs or in second-hand furniture, which should be examined carefully and treated if necessary. Old or disused articles of furniture, especially ones containing plywood (as in backs of picture frames) and wickerwork, should not be stored in attics or cellars without regular examination. They are a frequent source of infestation of structural timbers.

Certain insecticidal treatments may be made to timber to prevent insect attack. For rough structural timbers where discoloration is unimportant, creosote or creosote derivatives are effective, especially if applied by impregnation methods. For the treatment of decorative woodwork, impregnation with certain proprietary proofing agents may be carried out at the time of manufacture.

The modern contact insecticide treatments found effective against *Lyctus* have shown promise in protecting timber against attacks of other beetles, such as *Anobium*, *Xestobium* or *Hylotrupes*; on the other hand, it is not certain for how long the protection can be relied upon. Thorough application by dipping or spraying are most effective. The use of smoke generators cannot be relied upon to leave deposits on vertical or inverted surfaces; therefore they have little protective value, though they are likely to kill any beetles present and may prevent successful oviposition for a short time.<sup>(17)</sup>

### (ii) *Lyctidae*

The powder-post beetles present a rather different problem from the Anobiidae. Their dependence on the presence of starch in the wood has suggested the possibility of preventing attack by eliminating the starch before the wood is exposed to attack. The various methods depend on the natural metabolism of starch by the timber if the wood cells are not killed too quickly. One way is to season logs with the bark on for a few months. The seasoning may be accelerated by cutting into planks and heating gently for a week or so.<sup>(22)</sup> The most practical method appears to be seasoning with the bark intact, taking precautions against rot from too damp conditions.

The optimum temperature is about 40°C (104°F); stronger heat, say 45°C (113°F) or above, kills the cells and conserves the starch.<sup>(18)</sup>

Modern contact insecticides provide a useful method of preventing *Lyctus* damage; for example in sawn timber awaiting use. The best treatment is actual immersion, for 10 seconds in an emulsion containing 2% DDT or 0.5% BHC or 0.5% dieldrin. This should give protection for three years. Where dipping is not feasible, some protection can be obtained by thorough spraying of the above-mentioned insecticide emulsions, preferably in March–April before the emergence of adult beetles begins. This should be repeated annually.

These insecticides are also useful for addition to synthetic glues used during plywood manufacture. Thus, *gamma* BHC at  $\frac{1}{4}$  lb per 1000 cu ft single glue line, will give long-term protection.

### (c) **Eradication of infestations**

The measures to be adopted in dealing with wood-boring beetles will, of course, depend on the extent and severity of the infestation. Where there is likelihood of extensive damage to structural timber (e.g. by *Xestobium*) expert advice should be obtained from the Forest Products Research Laboratory.

### (i) Heat

Relatively small articles can be disinfected by heat in a temperature- and humidity-controlled kiln. The exposures necessary for the penetration of an effective temperature into planks of different thicknesses are given in a Forest Products Research Laboratory leaflet (No. 13). Care is, of course, necessary to prevent damage to varnish and glue in polished furniture, which should not be appreciably affected at temperatures up to 55°C (130°F) with humidities up to 80% R.H. (wax finishes are always affected; but the wood can be re-polished).

At 55°C and 80% R.H., the exposure periods necessary to kill *Lyctus* larvae range from 2½ hours for 1 inch thickness of wood, to 4 hours for 2 inches or 6½ hours for 3 inches. See also p. 84.

### (ii) Insecticides

A suitable insecticide should be effective, harmless to the treated article and not dangerous to man. The main difficulty is to penetrate the wood and perhaps the most suitable agent is a liquid with a toxic vapour. *Ortho*-dichlorobenzene has been found very satisfactory but it should not be used too freely in confined spaces, because continued exposure to the vapour is liable to cause chronic poisoning of the liver. Alternatively, various metallic naphthalenates or solutions of pentachlorophenol or *para*-dichlorobenzene in benzene have been used with success.

Relatively large articles can be treated by brushing the liquid over the unvarnished surfaces. Small and valuable articles may be treated by injecting *ortho*-dichlorobenzene into the exit holes and other crevices with a syringe.

Fumigation with methyl bromide is a method of destroying wood worm in valuable woodwork which might be damaged by liquid insecticides.<sup>(16)</sup> Laboratory experiments at 15°C (59°F) indicate that a lethal concentration time products (mgm/litre × hrs) for eggs of the common wood beetles is about 70, for larvae 200–300 and for adults 100–200. Small objects could be readily treated in a fumigation chamber. Also, field trials have shown good success in controlling *Xestobium* in H.M.S. *Victory* and the Round Tower, Windsor Castle.

### (iii) Excision and fungicides

Certain wood-borers (the two wood-boring weevils and the wharf borer) only attack sodden wood, badly attacked by fungi. It is therefore essential to cut out all the infested wood and destroy it. The surrounding timber should then be treated with a fungicide as a precautionary measure. The oil-soluble pentachlorophenol can be recommended for this purpose, as it is toxic to insect larvae as well as being a fungicide.<sup>(19)</sup>

### (iv) Other methods

Certain new physical methods of destroying woodworm have been investigated in recent years. Irradiation by X-rays will kill the larvae; but very high doses (about 10,000 r) are necessary and in view of the difficulties of ensuring safe treatment, the method does not seem practical.<sup>(6)</sup>

The use of infra-red radiation has been investigated but does not seem very promising.<sup>(5)</sup>

TABLE 15    *Signs of attack by the commoner wood-boring beetles*

Insect genus	Wood attacked				Exit holes
	Hardwoods Softwoods	Sound Decayed	Heartwood Sapwood	Bore dust	
<i>Anobium</i>	H & S	S & D	Usually S	Elipsoidal pellets	Round 1·5 mm
<i>Xestobium</i>	Old H rarely S	S & D	H & S	Coarse bun- shaped pellets	Round 3 mm
<i>Lyctus</i>	H	S	Usually S	Fine soft powder	Round 1·5 mm
<i>Hylotrupes</i>	S	S	Usually S	Large cylindrical pellets & powder	Oval 3 × 6 mm
<i>Euophryum</i>	H & S	D	—	Tiny ellipsoidal pellets	Irregular oval 0·8 × 1·5 mm

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# 15 · *Stinging, biting and urticating insects*

## *A · Insect stings*

### I · INTRODUCTION

The stinging insects belong to the order Hymenoptera, a highly evolved group of insects, some of which display very complex patterns of behaviour. Relatively few species are pests and many of them are beneficial, since they parasitize other, more harmful insects. The characteristic of the order which concerns us here is a tendency to elaborate the egg-laying apparatus, or ovipositor, to form a tool or a weapon. The more primitive branch of the order (the sawflies and wood-wasps) have ovipositors modified for sawing or drilling into the plant tissues in which they lay their eggs. The more advanced branch contains the wasps, bees, ants, gall wasps and insect parasites (Ichneumonidae and Braconidae; see p. 332). These higher types which may be recognized by their narrow wasp-waists, usually have the ovipositor modified to form an offensive weapon, the sting. The most normal use of this organ is that of the parasitic forms which employ it to puncture the host and lay an egg inside.

Wasps, bees and ants possess stings which are mainly used against other insects but can be turned against larger animals or man, with unpleasant results. The effect of the sting of a solitary form may be unpleasant, but, as is well known, some of these insects are social and the concerted attack of a large colony is naturally more serious than individual stings.

The insect colonies may be formed annually, or they may be of more permanent duration. They may be founded in two distinct ways. The more primitive method (which characterizes most tropical forms) is the departure of a group ('swarm') of workers with one or more fertile females. Alternatively, the sexual forms may be produced in large numbers over a limited time; and these fly off, mate in the air and the fertilized females begin new colonies independently. Thus, there is a tendency towards colonies containing only one fertile female (the 'queen').

### II · WASP AND BEE STINGS

#### (a) **Colony formation**

##### (i) *Wasps*

The common name 'Wasp' refers to six native species of *Vespula* which are probably indistinguishable to the lay eye. *V. vulgaris* and *V. germanica* are the most common forms; both of them usually nest in the earth, though sometimes among the rafters of a roof or outhouse. *V. rufa* also is fairly common and is another earth nester. *V. sylvestris* usually nests above ground level in such places as sheds, piles of timber, ivy, compost heaps, etc.; *V. norvegica* prefers small thorny trees or bushes such as

hawthorn or gooseberry.<sup>(20)</sup> The hornet, *Vespa crabro*, is a true wasp and similar to the others in general habits, in spite of its much greater size.

Certain non-stinging insects are sometimes mistaken for wasps or hornets; hoverflies (Syrphidae) for the former and giant wood-wasps (*Urocerus gigas*) for the latter. Hoverflies can be distinguished by their alternate darting and hovering flight. The giant wood-wasp lacks the narrow 'waist' characteristic of the social wasps. The female has a long rigid ovipositor which might be mistaken for a sting.

The colonies of *Vespa* are begun each year in the spring by a single fecundated female emerging from a winter hiding place. This female begins to construct her nest of wasp-paper, which she makes by chewing up wood scraped from weather-worn palings, fences, dead trees, etc. The wood fragments, bound together with an adhesive saliva, form a thin but strong paper-like material when dry. The female begins her nest with a few small cells hung upside-down on a kind of stalk or pedicel. Over this is built an umbrella-like cover. The female lays her eggs in these cells and when the grubs hatch she feeds them with fragments of captured insects. Eventually the next generation emerges as sterile workers who take over most of the work of provisioning and building. New cells are formed round the periphery of the original clump to form a horizontal layer or 'comb'. When this reaches a certain size, another similar layer is constructed below it and suspended from the first by short stalks or columns. Eventually 6 or 7 such combs may be formed, the whole surrounded by the cover which is, of course, enlarged periodically. A nest of this size may produce some 25 to 30 thousand wasps during a season.

Later in the year, special large cells are constructed to provide the queens for the subsequent season; the young in these cells are particularly well fed and they develop into fertile females. Towards the end of the summer the female begins to lay unfertilized eggs (and some workers may also reproduce without fertilization). All these unfertilized eggs develop into males, which mate with the young queens. The fertilized young queens fly away to find a resting place in which to hibernate; the rest of the colony dies out in the autumn.

Foraging worker wasps seek food for the larvae and for themselves. The grubs require protein, for growth, and so the workers collect insects or fresh and decaying meat, including fish. The activity of the workers is promoted by a sticky secretion produced by the grubs, in exchange for their nutriment. For themselves, workers require sugar for energy; and they obtain this from the nectar of various flowers (e.g. cotoneaster, ivy) or from fresh or processed fruits. This explains their attraction to jam factories or fruit canneries.

#### (ii) Bees

As a group, bees may be considered as wasps which have given up the carnivorous habit and turned to feeding on the pollen and nectar of flowers. As a consequence, their bodies are modified for collecting honey and pollen. The honey is taken up by tongue-like processes of the labium and stored in the crop (from which, however, it can readily be regurgitated for social purposes). The pollen is collected in masses and carried in basket-like arrangements of hairs on the specially flattened hind legs.

Another peculiarity of the social bees is their ability to secrete wax from glands

under the plates of the abdomen. This wax is used to build the cells or combs, either in a pure state or mixed with earth.

The varieties of bees are even more numerous than the wasps and, surprisingly, about 95% are solitary forms. Apart from the hive bees, the best-known social forms are the *Bombidae* or bumble bees.

The formation of new colonies in *Bombus* takes place annually by the work of an overwintered female, very much as in *Vespa*. Small colonies are constructed in the earth (often in abandoned mouse holes). A worker caste develops, somewhat (but not greatly) different from the queen. The total numbers of a colony may reach about 100 to 500 bees.

In the hive bees, *Apis mellifera*, the colonies have a single queen whose duties are very distinct from those of the workers. She may live for several years and produce a total of about  $1\frac{1}{2}$  million eggs. The colonies are perennial and new ones are formed by the departure of a swarm consisting of the old queen and a number of attendant workers; a young queen stays behind and continues the hive colony. The nest consists of elaborate combs constructed of pure wax and a single hive may contain 50 to 80 thousand bees, the majority being workers.

#### (b) Structure of the sting (Fig. 45)<sup>(19, 23)</sup>

The sting of a wasp or bee is carried in a cavity at the end of the body. The opening of this chamber is guarded by the last dorsal and ventral plates of the abdomen, which are separated only by a narrow curved slit, like a fish's mouth. Often the point of the sting can be seen protruding from this orifice.

On removing the lower plates, the sting can be seen lying horizontally between a pair of unjointed 'sting palps'. It is examined more closely, the sting is found to

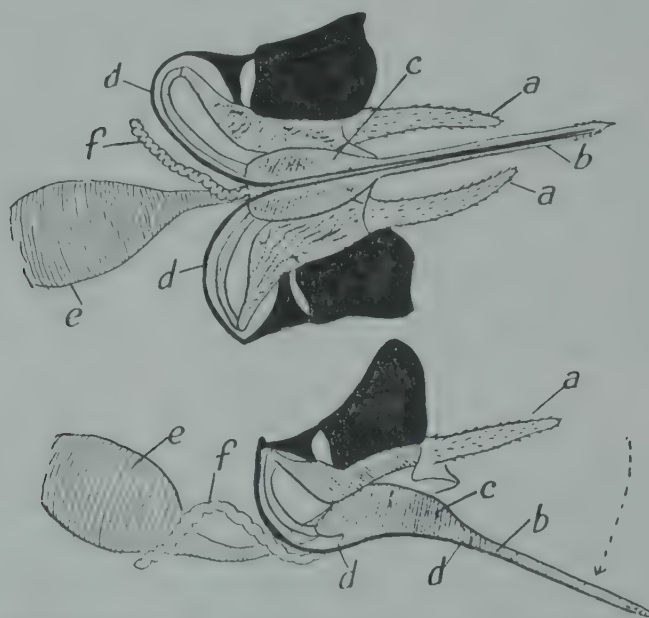


FIG. 45. The sting of a honey bee, semi-diagrammatic. Above: ventral view. Below: lateral view with sting depressed for use. (a) sting palps; (b) sting-sheath; (c) its bulb; (d) stylets; (e) poison sac; (f) alkaline gland. (After various authors.)

consist of three portions, which together form the ovipositors of non-stinging Hymenoptera. There is a quill-like sting-sheath, with a basal bulb, hollowed underneath like an inverted gutter. Below this lie two long stylets, running on grooves underneath the sting-sheath and closing its trough-like hollow. The tips of these stylets, which project beyond the end of the sting-sheath, are pointed and barbed.

The bulb-like base of the sting-sheath diverges into two curved arms and the lower portions of the stylets curve outwards along them. These serve as anchoring rods and are articulated with three sets of plates. The sting is brought into use by internal abdominal pressure, which extrudes it; then muscles play on the anchoring plates and rods which rotate it downwards, to be driven into the victim.

The poison injected by the sting is secreted by two long glands inside the abdomen, which discharge into a reservoir, the poison sac. (Another gland, called Dufour's or the alkaline gland, was formerly believed to be concerned in the action of the sting; but its use appears to be connected with the normal sexual function of the ovipositor.) From the poison sac the venom enters a bulb-like enlargement at the base of the sting-sheath and it runs down, between this organ and the stylets, into the wound. If the stinging insect is rapidly brushed away by a human victim, there is a tendency (especially with bees) for the whole stinging apparatus, together with the poison sac, to be torn out of the insect's body and remain attached to the sting in the wound.

Venom secretion in the honey bee begins just prior to emergence and reaches a maximum (about 0.3 mgm) after about two weeks. Some protein is required for maximum production and bees fed only on sugar secrete only a quarter of those taking pollen.

Recent studies have revealed the remarkable chemical complexity of bee venom.<sup>(2)</sup> Histamine is present and the venom causes release of more histamine from histidine in the tissues. Histamine, however, is not the only or even the main toxin. Electrophoresis splits the venom into 8 fractions, 5 of which are bases precipitated by picric acid. Of the remaining 3, 2 are notably active. One of them, 'melittin', is responsible for some local pain and inflammation and also general toxicity. The other component contains at least two enzymes – hyaluronidase and phospholipase A – which are responsible for supplementing and spreading the effects of melittin; both are present in snake venoms. Wasp venom also contains histamine and hyaluronidase as well as other distinctive components such as 5-hydroxytryptamine. Hornet venom contains a surprisingly high proportion of acetylcholine.

### (c) Effects of stings<sup>(14)</sup>

The venom has four characteristic toxic effects: (1) a histamine effect, responsible for redness, flare and weal seen in the skin, (2) a haemolytic effect, (3) a haemorrhagic effect (which can be responsible for uterine bleeding) and (4) a neurotoxic effect, which tends to cause paralysis.

The effects of stings are twofold; the direct toxic effect and anaphylactic shock which may develop in people who become sensitized to it. The direct effects are well known to be painful, the severity increasing from the honey bee to the bumble bee, wasp and hornet; but they are not dangerous to man, except in large numbers.

On rare occasions, people have received over 500 coincident stings, causing dangerous effects. The main symptoms, diarrhoea, vomiting, faintness and respiratory difficulty, usually pass off within 24 hours, but an attack of urticaria may follow at the end of a week.

The main danger from wasp or bee stings is the anaphylactic reaction, which may be provoked after a few stings or even a single one. Studies on the allergenic properties of the stings of various species of bees and wasps revealed 4 to 6 antigenic fractions in 5 species. Probably 2 fractions were shared by all species, while the remainder were specific. Individuals could become sensitized either to the generalized antigens or to the specific ones, or to both.

The severe allergic shock which is experienced by some people may cause death. Indeed, during the period 1950-4, deaths from stings of hymenopterous insects in the U.S.A. exceeded those from poisonous snakes (86 to 71); those from bees alone were about equal to those from rattlesnakes.<sup>(17)</sup> The symptoms arise within 20 minutes, reaching a maximum within 30 minutes and usually abating within 3-4 hours. Symptoms include respiratory distress, faintness with partial or complete loss of consciousness, followed by an itching rash. The skin may be flushed, or in some cases become pale. Swelling of the face is common, even when the sting has been on a limb. Sometimes there is vomiting with abdominal pain, or cramp or diarrhoea. Death is commonly due to respiratory failure brought on by vasomotor collapse. This may be accelerated in people stung on the mouth or throat, by swelling of the mucous membranes and occlusion of the air passages. The rapid onset of these symptoms (as contrasted with most snake bites) explains their danger.

#### (d) Treatment<sup>(14)</sup>

When the sting can be found, it should be removed. It appears as a tiny black shaft with the white poison sac attached to its free end. It should never be pulled out by grasping this sac, or more poison will be squeezed into the wound; it is best to scrape away the sting by a knife-blade or the fingernail.

Various simple local treatments, such as the application of vinegar or washing soda, have been suggested; apparently these 'remedies' reflect the erroneous idea that bee or wasp venoms are simple acids or alkalis which can be neutralized. Probably, however, any cool, damp application will have a temporary analgesic effect and give some relief; moreover, the use of a definite and specific treatment may have a reassuring psychological effect. More scientific is the employment of an antihistamine. Phenindamine, in the form of a 5% ointment has been said to cause local relief. Anti-histamine drugs (e.g. diphenhydramine) may be taken by mouth also, sometimes with good effect; but the absorption is slow.

Treatment of cases of anaphylactic shock is more serious and may require medical help. Stings on mouth or throat causing occlusion of the air passage may require tracheotomy. The best drug for treatment of acute systemic symptoms is adrenaline. An intravenous dose of 0.3 to 1 ml of 1:1000 adrenaline should be injected slowly.

Sensitivity to bee stings is at best inconvenient and possibly dangerous. Some people have found it advisable to undergo desensitization, under medical advice. The process consists of exposure to increasing doses of venom, beginning at very

low levels. Bee venom is available commercially for this purpose and wasp venom could be prepared and used in the same way, if necessary.

### (e) Control of wasps and bees

#### (i) Collection of bee swarms

During the summer months colonies of bees may settle in places where they cause some alarm. The bees are quite mild in the swarming phase and may be quite easily caught by an experienced bee-keeper. Wearing a veil and with cuffs and trouser legs tied tightly, no harm should be expected. If the swarm has settled on the branch of a tree, it may be dislodged by a sharp jerk and caught in a cardboard box held below (one should be sure that the queen is not left behind on the branch). The box is sealed and returned to a suitable hive.

#### (ii) Destruction of colonies<sup>(16)</sup>

Bees and wasps may forage half a mile or more, so that it may not be possible to trace their nests. In some cases, however, the source of a local nuisance may be found; for example, in the eaves of a house or some other undesirable place. Chemicals may be used to destroy such a colony. For a nest in the ground, carbon tetrachloride may be recommended, as it is rapidly effective against all stages. About  $\frac{1}{4}$  to  $\frac{1}{2}$  pint should be poured (or syringed) into the entrance hole, preferably at dusk, when most of the foragers will have returned. Alternatively a liberal application of 10% DDT dust should be applied (at the same time of day). *Gamma BHC* is not recommended for this purpose, as it is somewhat repellent to wasps and its use may result in large numbers of them hovering around the entrance of the nest, unwilling to enter. Calcium cyanide, which was formerly a common recommendation, is no better than the above-mentioned treatments and much more dangerous.

#### (iii) Wasps at picnic grounds or parks

Wasps can be extremely troublesome at the seaside, at picnic sites and in zoological gardens or parks, especially where food debris from picnickers is available. The first essential is to provide waste-bins and make sure that they are used. It will be found that wasps (also flies and blowflies) tend to congregate in and around these. Good control of wasps (and the other insects) can be achieved by spraying the inside of these waste-bins weekly, after emptying them, with 0.75% dichlorvos emulsion. The surfaces should be heavily sprayed, with special attention to the rim.<sup>(24)</sup>

#### (iv) Wasps in buildings

It may happen that elimination of a source of wasps is not feasible, yet some control is necessary; e.g. in a fruit-processing factory. Screening of windows and ventilators may be possible (see p. 79) using wire mesh of a size not greater than  $\frac{1}{8}$  inch. Even if it is not possible to protect the entire building, it may be worth screening particular sites which are very attractive to the insects.

Wasps in buildings may be destroyed in large numbers by bait traps. A bait is prepared from jam, syrup, molasses, fermenting fruit or beer; a selection of the most attractive medium in the local circumstances can be made by small trials.

Enough water is added so that the wasps will readily drown in the bait; the addition of a wetting agent (e.g. a domestic detergent) at about a teaspoonful per gallon will make the trapped wasps sink quickly. The prepared bait is poured into wide-mouthed jars or tins, which are placed where the wasps are likely to be active (e.g. near windows). The jars should be inspected periodically and the bait renewed when necessary.

### III · ANT STINGS

#### (a) Kinds of ant

The ants, or Formicidae, fall into some 260 genera and 6000 species, 80% of which are tropical; only 200 species occur in Europe and less than 40 in Britain. There are 5 important sub-families, which show an interesting evolutionary gradation, as follows.<sup>(21)</sup>

(1) *Ponerinae*. A primitive carnivorous group, with the castes not widely differentiated. Two species of *Ponera* occur in Britain, *P. punctissima* being occasionally found indoors.

(2) *Dorylinae*. The terrible 'driver ants' of the tropics, carnivorous wanderers without nests. Absent from Britain.

(3) *Myrmicinae*. A large and widely distributed group, the lower members being carnivorous and others omnivorous. Nine genera with many species in Britain, e.g. *Myrmica*, of which there are 6 or 7 British species. Workers 3–6 mm, reddish yellow to dark red, nesting in moist and shady places. Also *Monomorium pharaonis*, an introduced exotic species (see Fig. 33*b* and p. 291).

(4) *Dolichoderinae*. A world-wide group, omnivorous and mainly vegetarian. Only one indigenous genus, *Tapinoma*, in Britain. *T. erraticum*, a small black species, makes nests of small mounds on sunny places on heaths. Also *Iridomyrmex humilis*, an introduced exotic species (see Fig. 33*a* and p. 292).

(5) *Formicinae*. The most advanced group, with many genera, widely distributed; only two, however, in Britain, e.g. *Formica rufa*, the 'wood ant', workers brick-red, abdomen black, 4–9.5 mm. Common in woods, especially near pine trees. *F. sanguinea*, the blood-red ant, workers red, 5–9 mm. Nests in various places on banks, under logs, etc. Also *Lasius niger* and *L. brunneus* (see Fig. 33*c* and p. 290).

This series is arranged, generally, in order from the most primitive to the most highly evolved. Philosophically minded entomologists have pointed out that the social system of the ants has evolved in the same way as that of man. The stages represented are; the hunter and nomad (*Ponerinae* and *Dorylinae*), the herdsman (aphis tender), the farmer (fungus grower) and the omnivorous city dweller (the last three stages represented by various *Myrmecinae*, *Dolichoderinae* and *Formicinae*).

#### (b) Ant stings<sup>(3a, 21)</sup>

The workers of ponerine, doryline and myrmicine ants all possess stings at the end of the abdomen. The general form of the sting is similar to that described for wasps and bees. Furthermore, the poison injected likewise contains a toxic protein of low

molecular weight besides histamine and the poison-spreading enzymes, such as hyaluronidase.

In the Dolichoderinae, the stinging apparatus is greatly reduced, but there are, in addition, two repugnatorial glands capable of discharging an offensive fluid as a protective measure.

The Formicinae have no stings, but the poison apparatus is well developed and used for ejecting the liquid, which is either sprayed in the air at the enemy, or squirted into a wound made by the insects' mandibles. The fluid ejected contains formic acid, which can be distinctly smelt a metre or so away, when certain large nests are disturbed. The quantity and strength of the acid produced depends on the conditions under which the ant has been reared. In the wood ant (*Formica rufa*) the poison fluid may contain 20 to 70% of formic acid and amount to 12 to 18% of the body weight. Furthermore, the readiness with which ants will eject the poison depends on the weather (thus *Lasius niger* is more prone to squirt the acid under damp conditions).<sup>(7)</sup>

Not all ants will use their sting or spraying apparatus when interfered with; some run away and others feign death. Certain forms tend to be more pugnacious when their colonies are large and well established.

### (c) Effects of ant stings, etc.

(i) The primitive ants with stings produce effects analogous to those of wasp and bee stings; however, since the quantity of poison is generally much smaller, the effects are less. It is true that some large tropical ants can cause quite severe reactions, but the ants of this kind encountered in Britain are all puny. The tiny *Monomorium*, for example, can only sting delicate skins.

If many ants sting the same area, there is a dull pain as though the place has received a blow. This lasts from 5 to 45 minutes and is followed by a burning sensation which may persist on the following day.

Examples: *Myrmica*, *Monomorium* and *Iridomyrmex* (in delicate areas).

(ii) The ants which eject formic acid cause the symptoms to be expected from small splashes of that substance. Drops in the eye cause severe smarting; on areas of delicate skin, they cause milder smarting. The skin of the hands is not affected except when working in an ant nest for an hour or so.

Examples: *Formica rufa*, *Lasius* spp.

(iii) Ants which bite and inject formic acid into the wound, cause a very sharp pricking sensation followed by a considerable stinging feeling.

Example: *Formica sanguinea*.

## B. Insect bites

### I. MECHANISM OF INSECT BITES

Used in this sense, 'biting' insects is a misleading description. The so-called 'bites' are really punctures made by the mouthparts of bloodsucking insects; whereas the true biting insects, such as food pests, are those with chewing mandibles.

Various bloodsucking insects and acarines have been mentioned in the pages of this book. The habit has apparently developed several times, independently, in different orders, so that the mouthparts have been modified in various ways to pierce skin and suck out blood.

(i) *Formation of the wound*<sup>(4, 5, 6, 12)</sup>

Relatively shallow wounds are made by some insects (and also ticks), the mouthparts making lacerating movements to create a pool of blood, which is then sucked up. This laceration is done by snipping movements of the mandibles in blackflies and biting midges, by stabbing of the mouthparts of horseflies; while the stable fly rasps a hole by rapid movements of toothed lobes at the end of the proboscis. Insects with long fine stylets are able to bend these about in exploratory movements inside the host's tissue. Mosquitoes, bed bugs and, apparently, fleas are able in this way to find a capillary under the skin, from which the blood is tapped. Mosquitoes are also able to feed on the pool of blood leaking from damaged tissues, under the skin.

(ii) & (iii) *Injection of saliva and bloodsucking*

The mouthparts of all the bloodsucking insects are shaped in such a way that they form two tubes – e.g. by the apposition of grooves on two opposite elements. One tube is usually formed by the apposition of the mandibles or maxillae and is relatively wide; the other (often a hollow along the hypopharynx) is relatively narrow. Saliva is injected into the wound through the narrow tube, and the blood, mixed with saliva, is sucked up the wider tube by a 'pump' in the pharynx.

## II. HUMAN REACTION TO BITES

Some insect bites cause a sharp stinging pain (e.g. horseflies, stable flies) but the attacks of many bloodsuckers cause little or no sensation. Nearly all the unpleasant effects develop subsequently and are mainly due to the insect's saliva which is injected with the bite.

The human reactions vary very greatly in different individuals and this is the probable reason for many stories of laymen about selective biting insect parasites. If two people sleep in the same room and one *suffers* badly from insect bites, he will imagine that all the insects have chosen to bite him; whereas his companion may be equally bitten but not show any effects.

Three types of reaction may be observed:

- (i) *Haemorrhagic maculae*. These are small red marks surrounding the site of the bite, which may develop without any symptoms of irritation. In the course of several days, these marks become darker and finally brownish and they disappear only slowly.
- (ii) *Delayed-reaction papules*. A delayed reaction may be observed from a few hours up to as much as 14 days after the bite. Characteristically there is a red raised spot or patch ('papule') with inflammation and extensive swelling, usually accompanied by intense irritation. This reaction may persist for several days.

- (iii) *Immediate-reaction weals*. These weals appear within a few minutes of the bite, but do not last long, usually less than an hour. They are small whitish raised patches surrounded by an inflamed area and they cause moderate irritation.

The first of these effects described above is practically innocuous. The red colour is due to rupture of capillaries and diffusion of blood into the tissues. Liability of the patient to develop them seems to be related to proneness to bleeding (possibly associated with a low platelet count). The marks may be caused by bites of lice, fleas ('*purpura pulicosa*'), stable flies or ticks.

The two other effects of insect bites (which are the important ones) are allergic responses to the introduction of foreign proteins into the human body. These act as antigens, to which the body develops antibodies.<sup>(13)</sup> When the antigen-antibody reaction occurs in the tissues, there may be local production of a histamine-like substance, causing irritant skin reaction.

The foreign proteins introduced by insect bites are far from simple. In addition to saliva of the insect, there may be contamination from regurgitated fluid, so that it is probably better to describe the liquid as 'oral secretion'. Furthermore, insect saliva itself probably contains more than one component, as a rule. Thus, a variety of different chemical entities have been shown to exist in different regions of a mosquito's salivary glands. A further complication concerns differences in the sensitizing substances produced by different insects. Thus those in mosquito oral secretions are probably proteins, with a minimum molecular weight somewhat over 10,000.<sup>(1)</sup> On the other hand, the sensitizing compounds associated with flea bites are dialysable and consequently of relatively low molecular weight; they are probably haptens which combine with proteins in the host to form antigens.<sup>(3)</sup>

The responses to insect bites are often, like other allergic reactions, rather specific; so that a person sensitized to one species of mosquito<sup>(1)</sup> (or bed bug<sup>(8)</sup>) may scarcely react to the bite of another one. On the other hand, there may be varying degrees of cross-sensitization. Thus people sensitized to bites of human fleas may also react to fox fleas, to which they could never have been exposed.<sup>(10)</sup> The degree of specificity of bite reaction seems to be highest in the early stages of sensitization.

The rate at which the tissues respond in production of antibody differs in individuals and also according to the type of insect bite. The first bites of some insects usually do not elicit any reaction of this type. For example, no reactions to primary louse infestations are observed for 7 to 10 days. On the other hand, many insects can cause a delayed reaction after their first attack. This delay may be 1 to 7 days with *Cimex*<sup>(8)</sup> or 3 to 34 days with *Phlebotomus*.<sup>(22)</sup> If the insect bites are repeated at intervals, it is found that the time lag decreases and the severity of the reaction increases up to a maximum. Subsequently the severity may decline and even disappear; but if the insect bites cease for a few weeks, this acquired immunity is partially lost. The time required for development of maximum sensitivity appears to be about 1 to 2 months with *Cimex*, *Phlebotomus* and *Aedes*. In investigations with *Pediculus* and with infestations of *Sarcoptes*, a severe reaction developed in about 1 and 3 months respectively; but the reaction was so unpleasant and severe that it

was not feasible to continue heavy infestation of the volunteers to determine whether a subsequent desensitization could be obtained.<sup>(18)</sup>

An interesting development of this form of allergic response is the reactivation of old sites. The places bitten a few weeks previously may swell up again and become irritant when the same type of insect has bitten freely elsewhere on the body. This is interpreted as the result of local antibody production at the old bite sites. The reaction is caused by minute traces of antigen circulating in the blood from the new bites.

Immediate-reaction weals occur at a later stage of sensitization than the delayed-reaction papules; usually when the latter have reached their maximum or are beginning to decline in severity. Both types may successively appear in the same person; or the immediate weal may occur without any further reaction. It is not clear whether the weal is a reaction to a different antigen; or a changed response to the same one.

The progressive changes in reactions to bites of a particular insect seem usually to pass through various stages, as follows:<sup>(9, 15)</sup>

<i>Stage</i>	<i>Immediate reaction</i>	<i>Delayed reaction</i>
I	—	—
II	—	+
III	+	+
IV	+	—
V	—	—

Individuals may not pass through all stages of this scheme. For example, they may begin in stage II, by showing a delayed reaction to the first bite. (This may, perhaps, be due to a cross-reaction from a related insect bite.) In many cases, people do not succeed in reaching stage V, of complete immunity; and some may remain in stage III.

### III · TREATMENT OF BITES

As was remarked in relation to wasp and bee stings, it is unlikely that any simple substances applied externally to the site will be radically effective, because of the complexity of the toxins involved. Treatment must be symptomatic, using analgesic applications to allay irritation and inflammation.

Various antihistamines have attracted attention as possible methods of relieving reactions to mosquito bites. When taken orally, they may relieve the itching, though they do not reduce the visible reaction. Local application in creams cannot be relied upon.

Scratching may, of course, lead to sepsis which would require appropriate treatment.

#### *Desensitization*

Scientific evidence supports the popular impression that continual exposure to biting insects eventually results in more or less immunity. This would correspond to an

individual passing into stage IV or V, in which the unpleasant delayed reaction is lost. Attempts have been made to accelerate this process artificially, by graded injections of suitable insect extracts containing the appropriate antigen. There is a good deal of disagreement in the results, probably due to investigators depending on subjective assessments by patients. There is a further difficulty in determining the previous history of bites, especially since the insects responsible are rarely caught (or even seen) and even when specimens are provided they may be 'anything from grain beetles to small weed seeds'.<sup>(10)</sup> Clinical trials may also be complicated by the changing prevalence of various biting insects at different seasons or from year to year.

Taking everything into account, it may be said that there is some evidence of successful desensitization to fleas,<sup>(3)</sup> horseflies (*Chrysops*) and mosquitoes.<sup>(13)</sup> The delayed reaction (which is the more unpleasant) appears to be easier to prevent than the immediate weal reaction. Possibly further success may follow research on improved methods of preparing desensitizing inoculants.

### *C. Urticating insects*

#### I · CATERPILLARS WITH IRRITATING HAIRS

Contact with certain insects, particularly, if they are extensively handled or crushed, may cause severe irritation of the skin. In some cases, this is due to an actual toxic or vesicant substance present in the insects, for example cantharidin in the 'Spanish fly' beetle of southern Europe and certain tropical 'blister beetles'. Also, there are certain exotic moth larvae bearing urticating hairs on the body; these are hollow and contain poison which is liberated like nettle poison, if the hairs penetrate and break off in the human skin.

Urticating insects of these types do not occur in Britain. There are, however, certain moth larvae bearing hairs which can penetrate the skin and cause irritation.<sup>(11)</sup> This may occur in agricultural workers who frequently come into contact with certain caterpillars, in years of abundance. The irritating hairs contain no actual poison but may cause allergic sensitivity after repeated contact. The hairs are of several kinds, many of them barbed, so that they tend to stick in the skin. Some of their effects may be purely mechanical; but there is evidence that allergic sensitization to them can occur.

Probably the most common offenders are caterpillars of the brown tail moth, *Euproctis chrysorrhoea*. Other members of the same family (Lymantridae), which are able to cause this trouble, are the gipsy moth, *Lymantria dispar*, the black archer, *L. monacha*, the pale tussock, *Dasychira pudibunda*, also the lappet moth, *Epicnaptera quercifolia* (Lasiocampidae) and the garden tiger, *Arctia caja* (Arctiidae).

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# 16 · Nuisances

The various arthropods mentioned in this chapter as nuisances are grouped in the following ways:

## (a) Damp room pests

A number of pests are very sensitive to desiccation and will only thrive in damp places, such as basements, cellars, sculleries and bathrooms. Some of these pests also may be troublesome in newly built houses, the plaster of which retains moisture for a long time.

I The Silverfish (*Lepisma sacharina*); II Booklice (Psocoptera); III Plaster beetles (Lathridiidae and Cryptophagidae); IV Spiders (Araneae); V The Furniture mite (*Glyciphagus domesticus*).

## (b) Garden invaders

A great variety of different kinds of insect will occasionally enter houses and cause some dismay to the inhabitants, who may think them harmful. Among the specimens sent to the writer in the course of advisory work, were the following: soldier beetles (Telephoridae), chafers (*Melolontha*), stag beetles (*Lucanus*), water beetles (*Dytiscus*), bark beetles (Scolytidae), raspberry beetles (*Byturus*), longhorn beetles (Cerambycidae), rat-tailed maggots (*Eristalis*), ichneumon flies, leather jackets (*Tipula*), lacewings (*Chrysopidae*), water boatmen (*Notonecta*), aphids, poplar hawk moths (*Laothoe*), mason wasps (*Odernus*), thrips and ant pupae.

Obviously it is not feasible to describe all the casual insect invaders from the garden; but certain kinds of arthropod are repeatedly troublesome from their habit of invading dwellings in large numbers, usually for shelter (e.g. hibernation). The following examples do not include flying insects.

I Springtails (*Collembola*); II The Cricket (*Acheta domesticus*); III Earwigs (Dermaptera); IV Ground beetles (Carabidae); V Bagworm moths (*Psychidae*); VI The Clover mite (*Bryobia praetiosa*); VII Beetle mites (Oribatei); VIII Woodlice (Isopoda).

## (c) Outdoor swarms

Certain outdoor swarms of insects may come to the attention of Public Health Departments as nuisances. These include: I Seaweed flies (Coelopidae); II St Mark's Fly and the Fever fly (Bibionidae).

Flies breeding in sewage works, which could come under this heading, have been dealt with in Chapter 12.

## *A·Damp room pests*

### I· SILVERFISH (*Lepisma saccharina*)

#### (a) Historical notes

Robert Hooke gives quite a good figure of a silverfish in *Micrographia* (1665), a book recording his discoveries with an early microscope, printed by authority of the Royal Society. He describes it as the 'small silver-coloured book-worm' which 'is supposed to be that which corrodes and eats holes and covers of Books; it appears to the naked eye as a small glistening Pearl-coloured Moth; which upon the removing of Books and Papers in the Summer is observed nimbly to scud and pack away to some lurking cranney where it may the better protect itself from appearing dangers'.

#### (b) Distinctive characters

The silverfish belongs to the order Thysanura or bristletails, which is a very ancient group of insects. These primitive insects are widely distributed but no longer numerous. They are able to persist among their more efficient rivals by leading concealed lives, in the soil, under stones, leaves or tree bark.

These insects are descended from the primeval insect stock before wings were evolved (see p. 22). Consequently, there is no impediment to their moulting in the



FIG. 46. *Thysanura* (bristletails). Left: *Lepisma saccharina* (silverfish). Right: *Thermobia domestica* (firebrat). (After Anon., B.M. (Nat. Hist.) Econ. Leaflet No. 3.)  $\times 8$ .

adult stage and they continue to do so throughout life. Their characteristic body form is carrot-shaped, with two long antennae at the anterior (blunt) end and three tail-like appendages from the tip of the abdomen (Fig. 46). A careful examination of the underside of the abdomen of older bristletails reveals two or three pairs of abdominal appendages, called 'styles'. These are probably relics of the numerous abdominal appendages of the ancestral form.

About 23 species (out of a total of some 350) occur in Britain; two of them occur indoors, as pests: the firebrat and the silverfish. The former demands a very warm environment and is mainly restricted to old-fashioned bakehouses. It is dealt with in Chapter 11 (p. 295).

The silverfish owes its name to its silvery appearance, combined with rapid darting movements and undulating turns. It is by no means confined to dwellings, being quite common in nests of birds, especially pigeons; and it can survive quite rigorous winter weather.<sup>(45)</sup>

### (c) **Life history**<sup>(39, 42, 43, 44)</sup>

#### (i) *Oviposition*

The eggs are laid singly or in groups of two or three. Only a few are laid on any one day but the total eventually reaches about 100. Usually the eggs are thrust into crevices or hidden under objects; but sometimes they may be dropped quite haphazardly.

#### (ii) *Egg*

The eggs are broadly oval, about  $1\frac{1}{2} \times 1$  mm in dimensions. At first they are smooth and white, but within a few hours they darken to a brownish colour and become somewhat shrunken and wrinkled.

#### (iii) *Nymph*

The first-stage nymph is about 2 mm long, milky white and relatively plumper and less active than older stages. It is quite bare of scales and bristles. After three moults, a covering of scales appears and after the fourth moult the first pair of styles appears; the second pair are visible after eight or nine moults.

#### (iv) *Adult*

The stage at which reproduction begins is not known; probably it is about the tenth instar.

The mature insect has a body length of about half an inch. Its silvery appearance is due to the covering of tiny spade-shaped scales. In this connection, Robert Hooke compares it with the iridescence of pearls and similar effects depending on numerous 'very thin shells or laminated orbiculations'.

As already mentioned, the body has a carrot-like outline. The head bears long whip-like antennae composed of numerous small joints and a pair of compound eyes, each with only twelve facets. The mouthparts are primitive and not unlike those of the cockroach (see Fig. 2, p. 27). The mandibles are used for biting off small particles or for scraping away at surfaces, such as paper.

Silverfish live to a large extent on carbohydrates such as starch and dextrin, and are said to be able to digest certain forms of cellulose. Some forms of paper (chemically pulped) are apparently more digestible than others (mechanically pulped). In addition to carbohydrates, they welcome small amounts of protein in the form of portions of dead insects and the sizes, gums and glues found on wallpapers, book bindings, etc. They may bite very small holes in fabrics (cotton, linen, artificial silk) but cannot subsist on such a diet.

The internal digestive system is similar in plan to that of the cockroach and includes a sack-like crop, a toothed 'gizzard' and a midgut bearing blind food pouches.

The three thoracic segments are rather similar; each bears a simple pair of legs. The insect normally progresses by a series of short rapid runs interrupted by sudden pauses. The feet end in claws which enable it to run up rough materials such as paper or plaster, but it cannot climb vertical polished surfaces. In addition to the styles on the abdominal segments, the females bear ovipositors, made up of two pairs of processes originating below the eighth and ninth abdominal segments. The male has a pair of genital processes and a small median penis on the ninth segment. Copulation has not been observed but it is known that the sperm are transferred in a tiny bag, the 'spermatophore'.

#### (v) *Habits of adults and nymphs*

Silverfish are nocturnal in habit and are rarely seen in the daytime when they hide in various crevices. They may be found in various parts of the house but more especially in bathrooms and sculleries, possibly because of their need for moisture. They commonly hide behind skirting boards, under loose wallpaper, etc., during the day and emerge to forage for food at night. If they are surprised by a light during the night, they may remain motionless for a moment and then run rapidly to a harbourage. Owing to their inability to climb up polished surfaces, they are sometimes trapped in wash basins, in sinks or in china or glass utensils in kitchen cupboards.

Silverfish are probably transported from one house to another in bales of furniture or packages of food and other goods.

### (d) **Quantitative bionomics: ecology**

#### (i) *Temperature*

The silverfish has been less extensively studied than the firebrat<sup>(1)</sup> (see p. 296); but it is clear that its temperature preferences are lower. Thus eggs will hatch at 22°C (71°F), the lowest temperature tested; but they fail to hatch at 37°C (98°F) or above. The upper lethal temperatures are also lower (judging by experiments on a foreign related species *Ctenolepisma longicaudata*), which died after  $\frac{1}{2}$  hour at 45°C; 1 hour at 44°C or 15 hours at 41.5°C.<sup>(32)</sup>

Over the normal biological range, incubation takes 43 days at 22°C (77°F) and 19 days at 32°C (90°F). Maturation requires 90 to 120 days at 27°C (80°F); at this temperature, the instar length increases from 2 to about 20 days (by the tenth instar) and 40 days by the fifteenth instar (and to the end of the life). The adults live about  $3\frac{1}{2}$  years at 27°C; 2 years at 29°C and  $1\frac{1}{2}$  years at 32°C.

(ii) *Humidity*

Eggs of *Lepisma* will only hatch at humidities above 50% R.H. at 22°C (71°F) and above 75% R.H. at 29° and 32°C (84° and 90°F). The nymphs will live and mature above 60% R.H. but do not do well below 75% R.H.; the optimum is 90% R.H.<sup>(43)</sup>

(e) **Importance**

Both types of bristletail may cause damage to paper (especially wallpaper) and fabric, though in Britain they are seldom numerous enough to cause extensive trouble on this account. Occasionally silverfish will eat away the paste sticking wallpaper to the wall and they may destroy pastes binding insulating wrappings to pipes. Sometimes, too, they cause damage to ancient books or documents or other valuable articles in museums and similar collections.

In most well-kept houses they are regarded as an unpleasant nuisance, especially as their quick darting movements are liable to produce uneasy sensations.

(f) **Control**

Bristletails are not particularly easy to kill by insecticides if they are living under their optimum conditions. The adults are very long-lived and continue reproducing over a long period; so that if any escape destruction, the infestation will gradually increase again.

It is often possible to get rid of silverfish by rendering conditions unfavourable to them. Damp rooms or houses should be thoroughly heated and aired. If the air is kept warm and dry, this pest cannot survive for very long.

Modern contact insecticides (e.g. BHC) would probably be effective against silverfish.<sup>(2)</sup> Thus 10% DDT dust has been found effective against *Ctenolepsma* in Australia.<sup>(22)</sup>

## II · BOOKLICE (Psocoptera)

### (a) **Distinctive characters**

The Psocoptera form a small and rather degenerate group of insects related to the primitive order Isoptera (termites or white ants). On anatomical grounds, it is also believed that the parasitic Mallophaga (bird lice) are descended from early nest-living Psocoptera.

Booklice are small or minute insects with soft yellowish or greyish bodies. The more typical forms have four delicate wings, though they do not readily fly; but an evolutionary tendency has resulted in the loss of wings in many species. Another feature of the order is a tendency to suppress the male sex. In some species, dwarf males occur; in others males are rare or perhaps completely absent. In such cases the females reproduce without fertilization.

Some 800 or 900 Psocoptera are known, the vast majority of them living out of doors. The genera common in houses may be distinguished by the following simple key:

1. No wing rudiments
- Wing flaps present

*Liposcelis* (Fig. 47)  
(2)

2. Pale yellow or whitish in colour

Dark brown or black in colour

3. Rows of dark spots on the front margins of some abdominal segments. An active insect

Such spots absent. Sluggish

(3)

*Lepinotus*

*Trogium* (Fig. 47)

*Psyllipsocus*



FIG. 47. *Psocoptera* (booklice). Left: *Trogium pulsatorium*. (After Anon., B.M. (Nat. Hist.) Econ. Leaflet No. 4.)  $\times 30$ . Right: *Liposcelis granicola*. (After Broadhead and Hobby, *Discovery*, May 1945.)  $\times 40$ .

### (b) Life history<sup>(8)</sup>

Some of the earlier studies on booklice are somewhat unreliable because the environmental conditions were not carefully controlled (or even recorded in some cases) and these insects are particularly sensitive to such factors. Extensive controlled investigations have been made in recent years on *Liposcelis granicola* and many of the following biological notes are taken from the results. Unfortunately, however, it seems that this species is not a typical British insect, being adapted to a rather warmer environment.

#### (i) Oviposition

The female lays her eggs separately (one or two per day), extruding them by internal hydraulic pressure. The egg is sticky when laid and adheres to the substrate. Sometimes the females cover their eggs after laying them with fragments of food or rubbish.

Some of the outdoor species of the group lay small batches of eggs at intervals and cover them with a small silken web. (This production of silk by an adult insect is most unusual; the faculty is usually confined to larvae.)

#### (ii) Egg

The eggs of booklice, like those of all small animals, are very large in comparison to the parent. *Liposcelis granicola* lays an egg about a third the length of its own body. The egg is smooth and has a bluish-pearly lustre.

*(iii) Nymph*

The first-stage nymph breaks its way out of the egg shell with the help of a special file-like organ. The young nymph is seen to resemble the adult in general shape, though differing in some proportions and being, of course, much more delicate and paler in colour.

There are four nymphal stages in *Liposcelis granicola*. Other Psocoptera have between three and eight nymphal moults. The habits of the nymphs, for the most part, resemble those of the adults.

*(iv) Adult*

The heads of booklice are relatively large and bear a pair of rather long thread-like antennae, which are waved from side to side as they walk about. The compound eyes are poorly developed, those of *Liposcelis granicola*, for example, have only seven facets.

The mouthparts are of the biting type suitable for nibbling off small fragments of food. Booklice can apparently discriminate between small particles of suitable and unsuitable food. Thus they seem to be able to pick out fragments of dried yeast from a yeast-starch mixture, provided that the constituents are not too finely ground.

In laboratory experiments, dried brewer's yeast was found to be the most suitable food and the insects flourished on it. Wholemeal flour was much less satisfactory but was greatly improved if allowed to become mouldy. These insects, like many others, evince a vital dependence on vitamins of the B group. But although they demand a rich diet (e.g. yeast or dried egg) in order to proliferate, yet individuals can subsist for long periods on a meagre diet, such as pure starch, with little or no growth reproduction.

The thorax bears the walking legs, the last pair, in some species (e.g. *Liposcelis granicola*) having swollen femora, as in leaping insects. However, they have never been seen to jump, though they can run about actively. On encountering an unexpected obstacle, they usually retreat rapidly backwards for a short distance, pause, and then move forward again.

Adults of *Liposcelis* are like nymphs in being completely devoid of wings. Other common genera, however, develop small flap-like wing rudiments, like adult bed bugs.

The abdomen, as usual, contains the sexual organs. *L. granicola* is parthenogenetic and therefore no mating has been observed. In a related species the following procedure has been recorded. The sexes were apparently unaware of each other until at a distance of 2–3 mm apart. The male then became very excited and vibrated his antennae at intervals towards the female who sometimes responded in the same way. Finally, he ran forward, over the female's body, retreated so as to bring his abdomen underneath hers and copulation was then effected. The union lasted from 10 minutes to over an hour, in different cases. During this period, the female walked about, dragging the smaller male behind her.

An interesting habit of one or two species of booklice (e.g. *Trogium pulsatorium* and *Lepinotus* sp.) which is possibly connected with mating, is the production of

tapping sounds by beating the abdomen rhythmically against the substrate (cf. death-watch beetle, p. 379). Although this habit was noted as long ago as the seventeenth century, it is not very easily detected. The sound produced is rather faint on most surfaces, being loudest when the insect is resting on paper.<sup>(37)</sup>

### (c) Quantitative data<sup>(8)</sup>

At 25°C (77°F) and 75% R.H., the incubation period of *L. granicola* is 11 days and the nymphal period about 15 days. On a good diet (yeast) the females laid up to three eggs per day at first, but gradually declined to a rate of one per week. The adult life on this diet was 6 months, during which time a total of about 200 eggs was produced in 9 months. On a good diet the adult life was shorter, though more eggs were laid.

Accounts of earlier authors for other species give smaller numbers of eggs (20–60); but conditions may not have been optimum in their experiments.

The species *L. granicola* is rather susceptible to low temperature and dies after 3 hours at 0°C (32°F). On the other hand, it is rather resistant to high temperature and requires 42.5°C (108°F) at 75% R.H. and 100% R.H. or 40.5°C (105°F) at 30% R.H. to kill it in a 24-hour exposure.

The lower limits of humidity which will permit development are 55% R.H. at 25°C (77°F) and 65% R.H. at 35°C (95°F).

The short life cycle, long adult life and large numbers of eggs produced by *L. granicola*, suggest that it might have a great potentiality for proliferation. Laboratory studies indicate, however, that a great falling off of fertility is caused by overcrowding and that dense populations (as with mites) do not occur.

### (d) Importance

The natural habitats of the booklice include crevices in tree-trunks, under bark, or weathered fences and walls (especially among lichen or moss) and in birds' nests. They live on fragments of animal and vegetable matter, particularly on fungi and lichens.

Inside houses, these little insects may be found in many situations, running over walls, shelves or furniture. As the common name implies, they are often to be found crawling over the backings or between the pages of books. They apparently feed on mildews and moulds, scarcely visible to the human eye, which tend to form on wallpaper, bookbindings, leather and upholstered furniture and various foodstuffs. They are therefore especially prevalent under damp conditions which favour the growth of minute moulds and mildews. For example, they are often observed in new houses owing to the moisture drying out of the plaster.

Since booklice feed mainly on superficial moulds and fungi, they seldom cause any serious damage and they are virtually harmless in small numbers. Occasionally, when favourable conditions give rise to large infestations, they may cause losses to articles readily deteriorated by minor injuries (e.g. valuable furs and fabrics or insect collections and herbaria). Moreover, the appearance of these little insects in any numbers, crawling over furniture, is distasteful to many people; and though

they are quite harmless to man, they have sometimes given rise to alarmed complaints, and even litigation, from confusion with true lice.

### (e) Control

Booklice are not easy to eradicate by direct attack. Insecticidal treatments with no residual effect (such as fumigation) are of little value, since reinfestation from natural sources is very probable, where conditions are suitable. The use of powder insecticides is only slightly more effective.

The simplest and most certain method of eradicating booklice from a dwelling house is to ensure that it is so dry that the minute moulds and fungi, which serve as their food, cannot grow. If ordinary domestic heating is not effective, the house should be examined for structural defects which may be responsible for local damp patches. If it is difficult or impossible to obtain absolutely dry conditions, the moulds may be destroyed by the use of a fungicide. A solution of 2% formaldehyde in clear industrial spirit, applied as a spray, makes a suitable treatment.

## III · PLASTER BEETLES<sup>(7, 25)</sup>

### (a) Distinctive characters

The name 'plaster beetles' is sometimes given to tiny beetles belonging to the families Lathridiidae and Cryptophagidae. They are only moderately closely related, but have in common the habit of feeding on moulds and fungi in both the larval and adult stage. Some of the common species are the following.

#### *Lathridiidae*

*Enicmus minutus*. Adult (Fig. 35c) is about 1.2–2.4 mm long, varying in colour from pale reddish brown to black; when black, the antennae and legs are reddish brown. The mature larva is about 2.2 mm long, whitish, covered with moderately sparse outstanding hairs.

*Lathridius nodifer*. Adults about 2 mm long. Rather similar to *E. minutus* but with more distinct longitudinal ridges on elytra; dark brown or black in colour, with legs slightly paler. Larva whitish with numerous rather long recurved hairs.

*L. bergrothi*. Adults are also rather similar, 1.8–2.2 mm long, reddish brown in colour.

#### *Cryptophagidae*

*Cryptophagus acutangulus*. Adult (Fig. 35a) about 1.9–2.6 mm, dark brown. Mature larva, 2.8–3.0 mm, yellowish white, rather sparsely covered with erect hairs; two horn-like projections from the hind end.

### (b) Life history

The following species were successfully reared on mouldy bread in Petri dishes: *Enicmus minutus*, *Lathridius nodifer* and *Cryptophagus acutangulus*. The life cycle and habits of the three were rather similar. Eggs were laid, singly on the bread among fungal hyphae. The larvae (like the adults) fed on both the conidia and the

hyphae of the fungus. There are three larval stages. Pupation occurred in crevices, but with no special pupal cell.

*Speed of development* (at 17–20°C; 62–68°F): E, 5–6; L, 14–20; P, 5–7. Total, 24–33.

### (c) **Prevalence and importance**

These small beetles are widely distributed and thrive in moist, secluded places, where moulds and fungi can grow. They are common in the warm damp foundations of straw and hay ricks and they can occur in large numbers in debris and litter in warehouses (see p. 311). In dwellings, they proliferate in cellars and damp store rooms on cheese, jam or fabrics which have become mildewed.

A situation in which plaster beetles are liable to become a nuisance is in recently built or reconditioned houses in which the plaster has not completely dried. On these slightly damp walls, especially if they have been papered, small growths of fungi in the form of greyish or whitish patches may form, and these provide food for the beetles, which crawl all over the walls.

### (d) **Prevention and control**

To avoid annoyance from these beetles, every effort should be made to hasten the drying of newly plastered rooms. Every trace of mustiness should be removed by keeping the rooms warm and well aired; if necessary oil stoves should be employed. It is advisable to refrain from papering walls until the plaster has dried thoroughly.

Where the beetles are present, they can be killed by the usual contact insecticides in powder form or as aerosol sprays. The latter should be applied with care to avoid staining the walls.

## IV · SPIDERS (Araneae)

### (a) **Historical notes**

Spiders excite a certain fascination which is responsible for numerous legends concerning them, ranging from Arachne (who was turned into a spider for daring to challenge Athene to a spinning contest) down to Robert the Bruce. Many of the earlier myths and superstitions were gathered together by Dr Mouffet (p. 14) in his *Theatrum Insectorum*; and there is some reason to believe that his preoccupation with spiders resulted in the well-known lines about 'Little Miss Muffet', who is identified by W. S. Bristowe as his daughter Patience. Among the extensive anecdotal nonsense collected by Mouffet, there are a few genuine observations. Thus (of the 'Tame or House Spider'), 'It hath also feet, but not such a multitude as Scolopendraes hath . . . nor yet, six only, as the common sort of Insects; but it hath eight.' There is mention of 'inexhaustible matter or substance in their bellyes to make infinite webs . . .' and 'They feed only on the juice of the Flies and the dry carcase without any moisture, they cast away.' The ambivalent attitude to reproduction of small animals is reflected in the following. 'It is manifest that Spiders are bred from some aerial Seeds putrified, from filth, and corruption; because that the newest houses, the first day they are whited, will have both Spiders and Cobwebs in them. But their propagation is frequently by copulation, the desire and act thereof lasts almost all the Spring.'

(b) **Distinctive characters**<sup>(4)</sup>

The characteristic appearance of spiders is well known and, moreover, they are generally recognized by their association with webs or silk spinning. Scientifically, they are assigned to the rather heterogenous class Arachnida, which includes mites, ticks, scorpions and a few other groups. The characteristic parts of the spider's anatomy are as follows. The body is divided into a prosoma (or head-thorax) and an opisthosoma (or abdomen). The *prosoma* bears the eyes (either 6 or 8), the mouthparts and 4 pairs of walking legs. The mouthparts comprise (1) 5-jointed pedipalps, bearing on the base lobes known as maxillae, (2) chelicerae, which each consist of a stout basal segment and a thorn-like claw articulated on the top, and (3) a median labium. The chelicerae are the fangs, which bear poison ducts (though none of the British spiders are at all dangerous on this account). The *opisthosoma* bears book-lungs for respiration (as well as the entrance to a tracheal system, in some groups), sexual organs and silk-spinning spinnarets.

*Recognition of domestic species*

About a score of different spiders may be encountered indoors or in outhouses and stables; of these, about half a dozen are fairly common. It is not feasible to give a scientific key for their identification, but they can probably be distinguished by the following notes.

1. Very lanky legs, nearly 5 times as long as the body. Pale brown in colour.  
Body grows to 10 mm. 'Scaffolding type' web  
*Pholcus phalangoides* (Pholcidae) (Fig. 48e)
2. Moderately lanky legs, nearly twice as long as the body. Mottled colouring.  
'Sheet-type' web *Tegenaria* spp. (Agelinidae)
  - (a) Rather pale and not very distinctly marked. Opisthosoma yellowish brown with dark mottling. Body grows to 11 mm (leg length about 25 mm)  
*T. domestica*
  - (b) Opisthosoma with reddish-brown longitudinal band between yellowish spots with dark borders. Body grows to 20 mm (leg length about 43 mm)  
*T. parietina* (Fig. 48a)
  - (c) Opisthosoma with khaki longitudinal stripe with dark lateral markings.  
Body grows to 19 mm (leg length about 26 mm) *T. atrica*
3. Rather short legs, about as long as the body.
  - (a) Tiny, pink in colour. Body about 2 mm (leg length 2.5 mm). No web  
*Oonops domesticus* (Oonopidae) (Fig. 48c)
  - (b) Moderate size, with a shiny abdomen suffused with brown markings. Body about 7 mm (leg length 7 mm). 'Scaffolding type' web  
*Steatodes bipunctata* (Theridiidae) (Fig. 48b)
  - (c) Moderate size, glossy, mouse grey. Body about 11 mm (leg length 10 mm). No web *Herpyllus blackwalli* (Gnaphosidae) (Fig. 48d)



FIG. 48. Some common domestic spiders. (a) *Tegenaria parietina*; (b) two *Steatodes bipunctata* mating; (c) *Oonops domesticus*; (d) *Herpyllus blackwalli* raising a band of silk as protection from an adversary in the rear; (e) *Pholcus phalangoides* wrapping an insect in silk. Magnifications: (a)  $\times 0.6$ ; (b)  $\times 1.6$ ; (c)  $\times 4$ ; (d)  $\times 1.6$ ; (e)  $\times 1$ . All after Bristowe, W. S., *Comity of spiders* (1941) and *The world of spiders* (1958).

### (c) Life history<sup>(4, 5, 19)</sup>

Female spiders lay their eggs on a saucer of silk, which is then covered by more silk to form an egg sac. This may be suspended on a silk thread away from harm (e.g. *Tegenaria domestica*) or partly camouflaged with debris (*T. atrica*). Or the silk covering may be no more than a few random threads which enables the female to carry the egg bundle about (*Pholcus phalangoides*). In large spiders, dozens or even hundreds of eggs may be laid in a batch (*Steatodes* lays 100–150); but small ones lay few but often. The tiny *Oonops*, for example, lays two at a time.

The young spiders hatch from the eggs devoid of hair, spines or pigmentation and unable to feed or spin. After a few days, during which it continues to consume egg yolk, it moults into a very small but typical spider. Generally, however, it remains inside the egg sac for days, weeks or even months, according to season and weather. Finally, however, the time comes for the young spiders to disperse and seek food.

The habits of the young and growing spiders are not greatly different from those of the adults. All are carnivorous and prey mainly on insects. (Some large spiders (*Pholcus*, *Tegenaria*) will also feed on woodlice and they not infrequently prey on these in cellars.) Some forms wander about and either catch their prey by stealth

(*Oonops*) or by speed (*Herpyllus*). These do not build webs, though they form small silken cells to rest in when not hunting.

A variety of different types of snare are constructed of silk by the web-builders. Sheet webs are perhaps the best known. Those of *Tegenaria* include a tubular retreat for the spider for use in emergency. *Tegenaria* and its relatives characteristically move about on the upper surface of the web, while other spiders cling to the underside. Scaffolding webs are irregular meshes of threads spun in various directions. Some of the threads bear drops of sticky secretion to trap blundering insects.

As spiders grow, like insects they have to moult. The number of moults varies, size being the important factor. A very tiny spider may need only three moults to become adult as compared with ten in a very large species. Females usually moult once or twice more than males before maturity, and a few long-lived spiders (*Tegenaria*) moult once a year in the adult stage.

Mating in spiders is of considerable interest. The male must signal his presence (by visual or tactile signals) to prevent the female confusing him with a possible prey. Copulation is most unusual. The male spins a tiny web and extrudes sperm fluid on it. He then takes this up in special hollow organs at the tips of his pedipalps. On successfully grappling with a female, he introduces these palpal organs (either simultaneously or one at a time) into the vagina under her opisthosoma. The female stores sperm in a spermatheca and can utilize it for fertilizing several subsequent egg batches.

#### (d) Special peculiarities of domestic spiders

##### (i) *Tegenaria* spp.

The *Tegenaria* spider, though harmless, arouse distinct uneasiness from their rapid movements and general creepiness. A *T. atrica* female can cover 330 times her body length in 10 seconds (say 60 cm/sec).

*T. domestica* is almost world-wide in distribution and is very closely restricted to human dwellings.

*T. parietina* (sometimes called the Cardinal spider, from a legend connected with Cardinal Wolsey) is restricted to buildings in south-east England.

*T. atrica* is much less restricted to buildings than the other two species, but tends to enter dwellings in cool weather in the autumn.

##### (ii) *Pholcus phalangoides*

This spider occurs only in houses in the south of England and Ireland, where the average temperature exceeds 10°C (50°F) throughout the year. It spends much time motionless on its almost invisible scaffolding web. When an insect is caught in it the spider uses a long leg to wrap silk threads round the prey, without the necessity of approaching closely. In winter in cold situations, this lanky spider adopts an odd rigid position and hibernates until warm weather returns.

##### (iii) *Oonops domesticus*

A nocturnal hunter, it normally moves slowly and deliberately, though it can run rapidly forward or backward. Insects of suitable size are often found by touch and

appear to be hypnotized by gentle stroking before they are attacked and gripped with tarsal claws.

(iv) *Steatoda bipunctata*

This spider commonly builds its scaffolding-type web beside windows in out-houses, attics and unused rooms, and may be found in cellars. It is rare or absent from northern Britain.

(v) *Herpyllus blackwalli*

Widely distributed in Britain (and Europe), this fierce hunting spider trusts to rapidity of action. An ability to survive for months without water suits it for the arid environment of a human dwelling. It hunts by night, hiding behind pictures or in wall crevices during the day.

(e) **Importance**

Spiders are the dominant group of their class and surpass all other arachnids in number and variety of species, in their complexity of habits and in range of distribution. Nevertheless, they are only about as numerous as one of the smaller insect orders; about 550 British species are known.

Spiders have attracted comparatively little attention from man. A practical reason for this is their universally carnivorous diet which causes nearly all to be innocuous or distinctly beneficial to man as predators of insects. A very small number are harmful as, for example, the extremely poisonous *Latrodectus* spp. (especially *L. mactans* the black widow). The bites of the well-known *Tarantula* of southern Italy are much less serious, despite the legend of the tarentella dance prescribed as a cure. Unpleasant spider bites do occur there, however, due to *Latrodectus tridecemguttatus*.

From time to time, very large hairy spiders, with a crab-like stance, are discovered in hands of bananas. The most common, in bananas imported from the West Indies, is *Heteropoda venatoria*, common in many tropical countries. Despite its fierce appearance it is not dangerous and it is not unwelcome in many tropical homes for its destruction of cockroaches. Since about 1948 other large banana spiders from West Africa have been encountered at Covent Garden. These have conspicuous black spots on the abdomen and rings on the legs and belong to the genus *Torania*.

A few species of spiders habitually live indoors in Britain and some others are more or less frequent invaders in autumn and winter. The majority of them, however, like most insects, find the interior of houses too dry for them. They thrive best in damp and neglected rooms; whereas they are rare in well-kept houses, particularly if they are centrally heated. Apart from the direct adverse effect of very dry air on spiders (especially the egg stage), it results in the presence of fewer insects on which to feed.

There are a few minor objections to those spiders which may be encountered indoors. These, especially the large ones, are liable to arouse feelings of disgust or even dismay. Also, old discarded and dusty webs are unsightly and their presence is regarded as evidence of bad housekeeping.

V · THE FURNITURE MITE (*Glyciphagus domesticus*)<sup>(6)</sup>(a) **Distinctive characters**

*Glyciphagus domesticus* is a fairly typical acarid mite (see pp. 327 & 330, Fig. 38e) with a rather round body covered with long bristles, which are seen to be feathered, on high magnification. It is a widely distributed species, which may occur in large numbers on dried plant or animal remains in houses and stables.

(b) **Life history**<sup>(26, 28)</sup>

There is an egg, larva and first nymphal ('protonymph') stage. About half the protonymphs then pass to a second nymphal ('deutonymph') stage which eventually moults to produce the adult. The other protonymphs remain inside the cast skin and dedifferentiate into a rather amorphous oval mass; this is a 'hypopal' stage (see p. 327) which is resistant to adverse conditions of draught and often remains resting for as much as six months. Finally, it produces an active deutonymph which moults to give a normal adult.

*Speed of development.* Under optimum conditions (23–25°C or 73–77°F and 80–90% R.H.) the direct life cycle takes about 22 days. The hypopal forms greatly prolong this, however.

(c) **Importance**

*Glyciphagus domesticus* can occur on various foodstuffs, such as flour, sugar and cheese. In addition it may proliferate on furniture stuffed with vegetable fibres and, under rather damp conditions, may cause a nuisance in dwellings, especially in little-used rooms, and sometimes called the 'house mite'. In former years, it was very prevalent on furniture stuffed with green Algerian fibre.

(d) **Control**

The active stages of the furniture mite are very sensitive to desiccation. Accordingly a thorough warming, airing and general drying out of infested rooms soon curtails the nuisance.

*B · Garden invaders*I · SPRINGTAILS (*Collembola*)(a) **Distinctive characters**

Collembola are small, fragile insects, rarely exceeding 5 mm in length. Many of them have an abdominal appendage which enables them to leap a few inches through the air, and this is the reason for the common name of the group.

Collembola are evidently rather primitive insects, for they show no trace of metamorphosis and they are assigned to the archaic wingless sub-order Apterygota. Yet in several ways they are rather specialized and they have evidently evolved farther, in their own way, than other wingless groups. Thus, the antennae are usually

reduced to 4 segments; the mouthparts are deeply retracted into the head; and the abdomen is composed of only 6 segments, less than in any other kind of insect.

There are two main groups; the Arthropleona, with the body more or less cylindrical and the abdomen clearly segmented; and the Symphyleona, with the abdomen nearly globular and without clear segmentation.

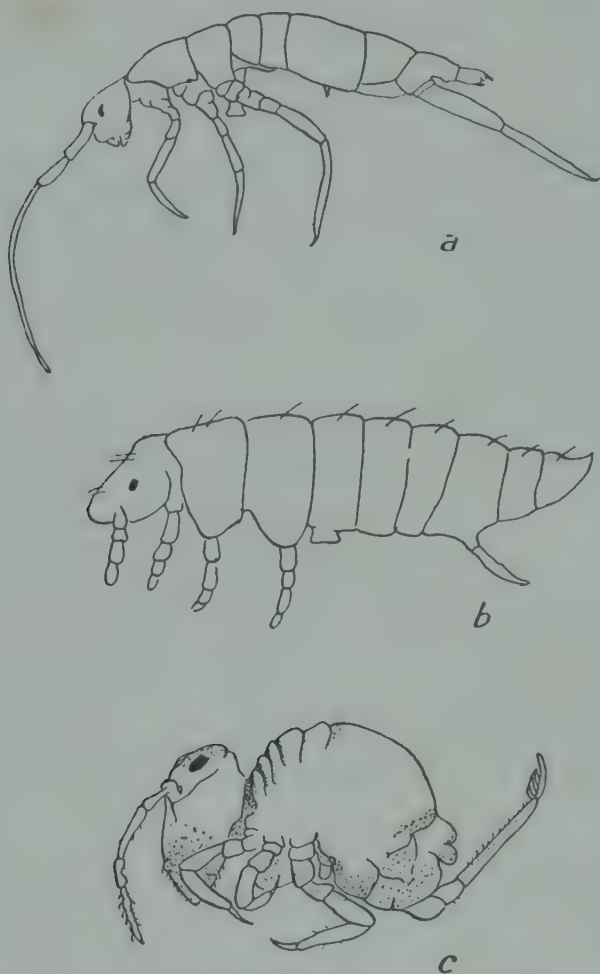


FIG. 49. *Collembola* (springtails). (a) *Tomocerus plumbeus*; (b) *Hypogastura purpurascens*; (c) *Sminthurides aquaticus*. (a) & (c) after Willem (*Mem. Sav. Etr. Acad. R. belge*, 58); (b) after Strebel (*Z. morph. Oekol. Tiere*, 25 (1)). (a)  $\times 7\frac{1}{2}$ ; (b)  $\times 35$ ; (c)  $\times 40$ .

### (b) Life history and appearance

The eggs of *Collembola* are smooth and spherical, usually laid in small clusters. The young forms resemble their parents in appearance and during development merely increase in size and pigmentation, with little change in structure. They continue to moult throughout life, apparently at irregular intervals. The appearance of some typical, well grown specimens can be seen in Fig. 49. The colouring may range from dull blue-black to greenish yellow or a variety of brighter colours. The body is usually covered with hairs or scales.

Compound eyes are absent and there are only simple ocelli, often surrounded by a pigmented area. The mouthparts are adapted for biting in most species though

they are withdrawn into the head. The food usually consists of fragments of live (or more often dead) plant tissue. A few prey on other small insects.

The unusual, characteristic organs of the group occur on the abdomen. The springing organ is a forked tail-like appendage carried under the fourth abdominal segment. Normally it is folded forward and kept in place by another retaining appendage under the third segment. When this releases the spring, it flies backward and projects the insect through the air.

The sexes are separate, though very similar in appearance, and copulation takes place before egg production.

### (c) Habits and physiology<sup>(41)</sup>

Most Collembola live in crevices and crannies, under debris or in the soil. The principal reason for their retiring life is their need of the very high atmospheric humidity which is to be found in such microclimates. Many species depend on cutaneous respiration and these are probably even more sensitive to desiccation than those with a tracheal system.

The domestic Collembola (i.e. sometimes occurring in houses) such as *Hypogastrura purpurescens*, thrive between temperatures of 3°C (37°F) and 15°C (59°F). They are resistant to low temperature and cold death only occurs at -5° to -15°C (23-25°F). Other species are also very cold-resisting and many occur in various situations in the Arctic Circle.

Collembola have senses which detect heat and cold and various smells and tastes. They retreat from the light mainly as an escape reaction (when disturbed by mechanical shock, etc.).

### (d) Quantitative data<sup>(41)</sup>

Eggs of *H. purpurescens* hatch in 4 to 15 days. The first moult occurs in about a week and other moults occur at irregular intervals. Females mature in 6 to 7 weeks. Total life 7 to 8 months.

*Tomocerus minor* moults at intervals of 1 to 4 weeks and lives about a year.

*Sminthurinus niger* eggs hatch in 10 to 14 days and females mature in 2 to 3 weeks.

*Hypogastrura viatica* observed throughout life at temperatures of 5-15°C (41-59°F), moulted on the average 9 times and lived an average of 78 days.

### (e) Importance<sup>(35)</sup>

Collembola are very widespread and numerous in nature. They are found in the soil, in decaying vegetable matter (dead leaves, rotting wood), among herbage, under the bark of trees, etc. Nearly all live harmless scavenging lives, scarcely observed by man. A few species (e.g. *Hypogastrura viatica* and *Tomocerus minor*) are very common in the gravel of percolating filters at sewage works, where they perform a useful function in feeding on the biological film and preventing clogging, especially in winter, when other insects in the filters are quiescent (see pp. 341-342).

For the purposes of this chapter, we are interested in a few species which occasionally intrude into dwelling houses. Species of *Hypogastrura*, *Lepidocryptus*, *Seira*, *Tomocerus*, etc., have been reported as occurring in houses. Some forms breed in

cellars; others are common in flower-pots of plants kept indoors. They also occur in bathrooms and in the neighbourhood of sinks and drains. Though they are quite harmless to man, they are sometimes accused of causing bites, probably on account of their jumping habits which recall the behaviour of fleas.

#### (f) Control

The sensitivity of Collembola to desiccation usually renders it an easy matter to eradicate them from dwelling houses by drying and airing affected rooms. An American pest-control operator described an infestation of *Seira nigromaculata* in decayed insulation of a refrigeration plant. This was eradicated by injecting the insulating material at 6-foot intervals with a 5% solution of rotenone in methyl formate.<sup>(40)</sup>

## II. THE HOUSE CRICKET (*Acheta domesticus*)

### (a) Historical notes

In contrast to the modern aversion to the noise of crickets, there are many records of appreciation in the past by people of different countries. A sort of 'cricket fancying' cult has existed in China for many years and there are various treatises on the subject, one dating from the Sung dynasty (thirteenth century). The insects were

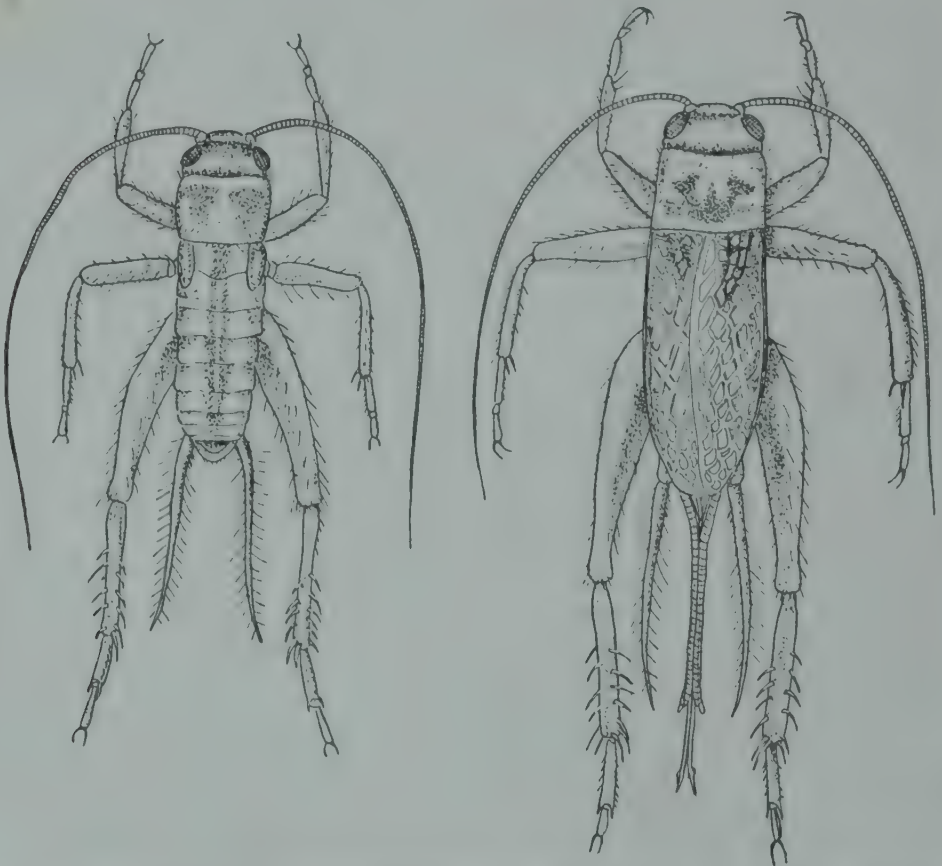


FIG. 50. The house cricket, *Acheta domesticus*. Left: male nymph.  $\times 6$ . Right: adult female.  $\times 5$ . (After Anon., Brit. Mus. (Nat. Hist.).)

tended with elaborate care in small carved gourds and were carried about in little ivory cages attached to the garments to please the owner with their song. Crickets were also kept for fighting miniature matches, incited by 'cricket ticklers'! (Rat whiskers mounted in ivory or bone handles.)<sup>(31)</sup>

Thomas Mouffet writes (sixteenth century):

Children (as the Italians do Grasshoppers) do keep them in a box full of holes, or bags to hear them singing in the night, giving them leaves or herbs whereon to feed and so keep them all the summer. They are kept in Africk in iron cages and are sold at a great rate, as I have heard from some Merchants, to cause sleep. For those of the inhabitants of Fesse are exceedingly delighted by their shrill noise.

In Portugal it is an old custom for lads to catch crickets and send them to the ladies of their choice as a sign of devotion. Similar appreciation of crickets flourished at least as late as the nineteenth century. Thus Dickens in *The Cricket on the Hearth* (1845) compares the chirruping with the homely sound of a singing kettle. Gilbert White (c. 1790) and W. H. Hudson (*Hampshire Days*, 1903) both praise the field cricket. Hudson, however, remarks that the song of the house cricket is coarser and 'more creaky'.

### (b) Distinctive characters

The crickets are distantly related to the cockroaches; both were formerly included in the order Orthoptera, which is now restricted to the jumping types, of which there are three groups:

(a) 'Short horned' grasshoppers with short antennae and the females with short ovipositors. This family includes true locusts.

(b) 'Long horned' grasshoppers with long, thread-like antennae, often as long as the body, and the females with long ovipositors.

(c) Crickets with antennae and ovipositors usually long. Their wings are carried flat on the back and folded down over the sides, whereas the grasshoppers hold them obliquely, like the sides of a roof.

### (c) Life history<sup>(29)</sup>

#### (i) Oviposition

Observations on crickets in captivity suggests that the females usually dig out a pit about  $1\frac{1}{2}$  cm deep in soft earth before laying their eggs. The pit is dug by scratching with the front legs, large particles being removed in the mouthparts. Then the abdomen is inserted in the hole and the ovipositor plunged into the bottom. Under laboratory conditions, eggs may also be laid in various moist situations as under damp paper or in moist foods.

#### (ii) Eggs

The eggs are banana-shaped, smooth and white. They are about 2.4 mm long and 0.3 mm wide. They are rather sensitive to desiccation and on long exposure to dry air they shrivel and collapse. On the other hand, they are liable to be attacked by moulds in air saturated with water vapour.

*(iii) Nymphal stages*

The first-stage nymph is recognizably like its parents, but differs in many proportions; for example, the head is relatively larger and the hind (jumping) legs relatively smaller.

Development is slow and has not been studied in detail. There is an indefinite number of moults; the maximum recorded is 11; but 7 to 9 are more common. The characters of the adult appear gradually and by the fourth stage the rudimentary ovipositors of the females can already be distinguished.

*(iv) Adults*

The head bears a pair of long whip-like antennae and fairly well-developed compound eyes. The mouthparts are of the primitive biting type, not unlike those of cockroaches.

Crickets are omnivorous but appear to prefer soft foods such as raw or cooked vegetables and fruit, bread, dough and similar substances especially if damp and decaying; also cooked or raw meat (including dead or even live insects). They seem to dislike hard-baked flour products and do not eat unhusked cereals. This is apparently not due to inability to bite hard things, for they can bite through the chitin of insects and nibble leather and even wood. Indeed, crickets have a curious habit of biting holes in various fabrics (wood, cotton, artificial silk, etc.) which do not serve them as food.

Attempts to rear crickets in captivity are handicapped by a strong tendency towards cannibalism. Crickets with any injury to the legs or other organs are soon set upon and eaten by their companions. This practice is most common under dry conditions and with a lack of moist food.

The thorax of the cricket bears well-developed legs, of which the last pair are enlarged in the form characteristic of jumping insects. The powerful leaping muscles are in the swollen 'femur' segment, and the long narrow 'tibia', which applies the leverage, lies folded forward beneath it in repose. This segment bears two rows of pig-like spines on the hind (under) surface, which gives purchase on rough ground.

Running and not jumping is the normal mode of progression of crickets. Usually the insects move about in short runs (in which the older nymphs cover about 2 inches) interrupted by short pauses of  $\frac{1}{2}$  to 1 second. This mode of progress (which resembles that of the housefly) may require about 20 seconds to cover 50 cm (20 inches). The younger nymphs can climb slowly up vertical glass surfaces but this power is lost by the older stages which can only climb up rough materials.

Jumping is resorted to as an escape reaction when danger threatens. Often from 5 to 15 jumps follow one after another, but the insect gradually shows fatigue and the distance covered gradually declines. The older nymphs can cover about 15–20 cm reaching a height of 6–8 cm in their first leaps, but this falls off to about 2–3 cm; after about 24 jumps they are unable to leap further. As the insect travels through the air, the body swings round through an angle of  $100^\circ$  to  $170^\circ$  so that the next jump follows at an acute angle to the last one. This serves to confuse a pursuer.

The thorax of the cricket also bears the two pairs of wings which are folded over the body in repose. These wings are not used for flight, nor apparently even for

gliding. The forewings are stiffer than the hind pair and have a certain protective function. Contrary to the usual rule among Orthoptera, the right wings overlap the left.

The wings of the two sexes are easily distinguished even when closed, for those of the males are modified for producing the characteristic chirruping. Each forewing bears a file-like serrated edge which rests against a ridge or scraper on the other wing. During the chirruping the two forewings are raised to an angle of  $45^\circ$  with the abdomen and are moved laterally in and out, so as to rub the scrapers over the files. Other parts of the wing are developed as vibratory 'tympana' to amplify the sound.

The chirruping is associated with sexual activity and it has been demonstrated that female crickets can be enticed by the sound of males relayed over the telephone. The sound is perceived by auditory organs on the front legs.

The abdomen of the cricket terminates in a pair of prominent cerci which are able to detect air vibrations over a great range of frequencies. In the female there is also present a long needle-like ovipositor.

The mode of copulation has been noted by several observers.<sup>(30)</sup> The male chirrups and waves his antennae. Later he displays a curious movement, vibrating his body from side to side or back and forth. Later the chirruping changes in character and at this point the female usually mounts his back. If this does not happen, he frequently moves backwards towards her, pushing his abdomen underneath hers. Copulation lasts about two minutes, in which time the male transfers the sperm in a tiny bulb (known as a 'spermatophore'). This remains attached to the female for about an hour after mating and finally falls off. Sometimes the female detaches the spermatophore and eats it. The male secretes a new spermatophore which may take between a half and one hour. After this, the insects are able to copulate again though this may not happen for several hours or a day or so.

#### (d) Quantitative bionomics

In laboratory colonies, with a favourable diet, preoviposition periods of 10 days at  $28^\circ\text{C}$  ( $80^\circ\text{F}$ ) or 5 days at  $35^\circ\text{C}$  ( $95^\circ\text{F}$ ) were observed.<sup>(20, 33)</sup> The average numbers of eggs laid were 728 and 1060, respectively, over a 5-week period; and the females survived for a further 2 to 3 weeks without oviposition.

Breeding in houses or warm fermenting dumps may be continuous rather than seasonal; all stages may be found in spring and autumn. The warm original home of crickets is evident in their preference for warmth expressed, in their choice of harbourages. They are found indoors in bakeries, kitchens and boiler houses (among coke, etc.) as well as under the hearths of primitive dwellings. They are not active at temperatures below  $20^\circ\text{C}$ . Nevertheless, they display fair resistance to cold. Nymphs and adults survived an exposure overnight to temperatures ranging between  $-4^\circ\text{C}$  ( $24^\circ\text{F}$ ) and  $-8^\circ\text{C}$  ( $18^\circ\text{F}$ ).<sup>(29)</sup>

The resistance to starvation is not very great, at least in the younger stages. Second-stage nymphs died, on the average, after about a week without food at room temperature (and in less if also deprived of water). A few, however, survived nearly 3 weeks.

*Speed of development.* At 23°C (73°F): E, 46-51; N, 81-238. At 26°C (79°F): E, 23; N, 108-115. At 35°C (95°F): E, 12; N, 27-35. At 40°C (104°F): E, 13; N, 35-41.<sup>(10, 33)</sup>

### (e) Importance

The house cricket originated in hot Palaerctic deserts (Persia and Sahara) and is ill-adapted to the European winter. In Britain and similar northern latitudes, crickets live out of doors in the summer but tend to seek shelter in the autumn; many of them tend to invade houses. It seems that in former times it was very common for a few crickets to spend the winter in warm crannies of the kitchen. The chirruping noises (made by the adult males) were not regarded as particularly unpleasant; rather the reverse.

Whether modern nerves are less robust, or whatever the reason, the noises of crickets are usually found highly objectionable today. However, infestations in small dwelling houses are less frequent, possibly because of improved construction. In recent years, trouble from crickets is almost always associated with refuse dumps. The large bulk of rubbish offers a very favourable environment for crickets. In addition to shelter and scraps of food, the dump provides warmth from fermentation and putrefaction. Crickets may survive in crevices in large rubbish dumps throughout the winter, but in the autumn, large numbers are liable to migrate and invade houses in the vicinity. These hordes of migrants are almost reminiscent of locust swarms.

Whatever the opinion about the presence of a few crickets in a house may be, there can be no doubt about the objectionable nature of these autumnal mass invasions. Not only do the creatures damage foodstuffs, but they are very prone to bite large holes out of many fabrics and the noise of their concerted chirruping is intolerable. Indeed, it was officially recorded at an inquest at Alderney Edge on 12 January 1934, that a Sanitary Inspector of Hale U.D.C. had been driven by crickets to desperation and suicide.

### (f) Control measures

#### (i) *In houses*

Control of crickets inside houses may be done by powder insecticides or by sprays, as recommended for cockroaches (see p. 287).

#### (ii) *On refuse dumps*<sup>(11)</sup>

The liability to nuisance from crickets on a refuse dump can be greatly reduced by controlled tipping properly conducted (see p. 338). A badly kept dump, with a large exposure of recently tipped rubbish, provides breeding grounds for hordes of crickets. Empty food tins offer shelter and scraps of food, so that they ought to be crushed and covered up as soon as possible.

Where outbreaks of crickets occur in spite of reasonably well applied tipping methods, it may be necessary to cover up as much as possible of the dump with a 6-inch layer of earth, fine ashes, soot or lime. Coarse clinker is useless; the crickets thrive under it.

If covering is difficult or impossible, it may be necessary to resort to insecticides. Probably the simplest effective treatment is to make one or two weekly applications of a powder insecticide with the aid of a rotary blower. Dusts containing either 0.6% *gamma* BHC or 5% DDT should be used at the rate of 1 cwt per acre.

### III · EAWIGS (Dermaptera)

#### (a) Historical notes

Thomas Mouffet (see p. 14) speaks of the common earwig as a garden pest, 'because of the clove gilliflowers that they eat and spoyl'. He observed that countrywomen set up traps of 'ox hoofs, hog's hoofs or old cast things' set on sticks. The modern country garden may often be seen with earwig traps, made (rather less fantastically) of small flower-pots, stuffed with straw, and inverted on the tops of sticks. In 1758 the French naturalist De Geer made some interesting observations on the maternal care of earwigs which is described below.

The word *earwig*, derived from the Anglo-Saxon, is of considerable antiquity, and reflects the widespread belief that these insects are prone to wriggle into the human ear (and perhaps penetrate the brain). Compare the German *Ohrwurm* and French *Perce l'oreille*.

#### (b) Distinctive characters

The earwigs form a small order of insects (about 1000 species) of a very characteristic appearance, exemplified by the well-known common European earwig. In

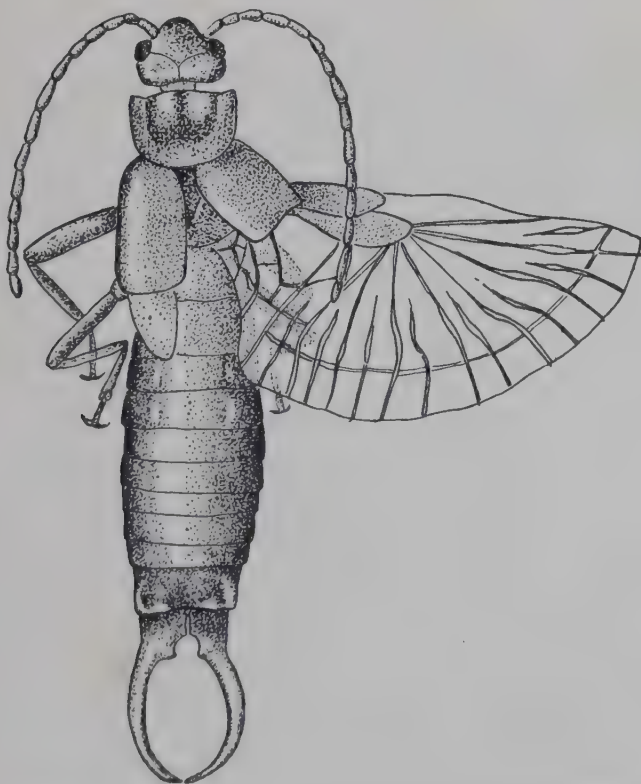


FIG. 51. *Forficula auricularia* (the European earwig). After Chopard (*Faune de France*).  $\times 5$ .

Britain, there are but 5 native and 4 or 5 introduced or casual species. The more common examples are:

*Forficula auricularia* (the common European earwig) (Fig. 51)

Lengths: body, 10–14 mm; forceps 4–9 mm.

Colour: dark sienna brown; head darker, legs paler.

*Labia minor*

Lengths: body, 5–5.5 mm; forceps 1.5–2.5 mm.

Colour: yellowish tawny.

### (c) Life history<sup>(34)</sup>

#### (i) Oviposition

The eggs are deposited in small covered cells in the upper 2 inches of soil, in early spring. A batch of about 30 is laid by each female and the mother remains with the eggs and tends them. If the female is removed from the eggs (except in the last few days of incubation) they usually become either mouldy or desiccated and die.

#### (ii) Egg

The eggs of *Forficula auricularia* are oval and white, about  $1 \times 1\frac{1}{4}$  mm in size. The young first-stage nymphs remain with their mother who appears to brood over them like a hen with chicks, as described by De Geer. However, it is possible that the earwig's maternal solicitude has sometimes been exaggerated. After a few days, the young disperse and live alone.

#### (iii) Nymph

There are normally four nymphal stages, though as many as six have been observed. The nymphs resemble the adults in most particulars, though, of course, the wings are not fully developed until after the last moult. There are fewer segments in the antennae; 8 in the first instar, increasing gradually to 14 in the adult of *F. auricularia*.<sup>(24)</sup>

#### (iv) Adult

The general appearance of the adults must be well known to everybody. The mouthparts are formed for biting and resemble those of the order Orthoptera to which the earwigs are related. As already mentioned, earwigs are both carnivorous and vegetarian, the relative importance of the two habits being uncertain.

The head carries compound eyes of moderate size (500–1000 facets); but the insect has rather poor visual capacity. Thus, an object which a honey bee could resolve into 64 points of light would appear as a single spot to the earwig.

Earwigs are nocturnal in habits and spend the daytime resting in dark crevices, preferably away from the ground. The reflexes responsible for this behaviour are as follows: they avoid light and are attracted by dark objects; they prefer to walk upwards and tend to remain at rest with as many parts of the body as possible in contact with solid objects.

The thorax bears the scale-like rudiments of the first pair of wings, underneath

which (and protected by them) lie the second pair, folded up in a complex way. The common earwig very rarely flies; it relies on walking and is also widely distributed while hiding in horticultural stock and other articles moved about by man. About half the known species of earwigs in temperature zones are similarly averse to flying. The most likely one to fly is the small, dark *Labia minor* which may occasionally be seen on the wing, sometimes in large numbers.

On the end of the abdomen are the characteristic forcep-like cerci, curved and sickle-shaped in the males, straight in the females. The primary function of these forceps is uncertain. Once or twice they have been observed to impale the insect's prey and sometimes (in *Labia minor*) they are curved over the body to help release or secure the wings. Possibly their function is to intimidate larger animals by their vicious appearance.

#### (d) Quantitative data

Studies on the European earwig in the neighbourhood of Washington D.C. indicate an incubation period of 73 days in winter, and 20 days in spring. The nymphal period occupied about 50 days in the laboratory and 70 days or more out of doors.<sup>(14)</sup>

In Britain, the sexes mate in the autumn and hibernate together in cells in the soil, which the males leave first in early spring. The eggs laid about this time hatch about April and the new adults appear towards the end of June. Some females rear a partial second brood.<sup>(24)</sup>

#### (e) Importance

As household pests, earwigs are merely intruders from the garden which do not breed indoors. Sometimes, however, they enter houses in large numbers and become very objectionable. Low-built country houses are most prone to these invasions, particularly if they are surrounded by herbage or covered with creeper. New housing estates are often troubled by plagues of earwigs, perhaps consisting of those dispossessed of their natural habitat by the building operations.

Earwigs are a minor horticultural pest. They sometimes damage beautiful flowers by eating holes in the petals; but, on the other hand, they are beneficial to the gardener by preying on other insects.

#### (f) Control

Insecticides used indoors are merely palliatives of domestic invasion of earwigs. The insects should be attacked in the garden by baiting (see below) if very numerous, but often it may be sufficient to cut away vegetation or creepers from around the windows of affected rooms. Additional protection may be obtained by smearing a band of creosote, as a repellent, along the base of the outside wall.

Large infestations, such as in new building estates, may be attacked by a poison bait made of a fluorine compound with bran and fish oil or molasses (see p. 117). Crumbs of this mixture should be sprinkled in likely places and covered by boards or tiles. These covers will attract the earwigs and at the same time prevent the poison bait being eaten by domestic animals.

#### IV · GROUND BEETLES (Carabidae)

The ground beetles belong to an enormous family of rather primitive beetles, mainly occurring in the soil, under stones, in rotting wood, moss, etc. They are mainly fairly large, black beetles (though a few are metallic or violet coloured) with some similarity to the Tenebrionidae (cf. *Tenebrio molitor*, Fig. 34c). Most of them are predaceous, both as larvae and as adults.

A few species are quite often encountered in barns, outhouses, granaries and even in house basements under rubbish, preying on other beetles and their larvae. Among the species that have been found indoors in numbers are, *Harpalus rufipes* (black, about 10 mm long), *Pristonychus terricola* (bluish black, about 15 mm long) and *Sphodrus leucophthalmus* (black, about 22 mm long).

These do no harm; in fact they are beneficial to the extent that they prey on other insects. However, their presence in large numbers is generally regarded as disagreeable and is certainly a sign that thorough cleansing measures are desirable to eliminate the debris under which they shelter and other insects on which they feed.

#### V · BAG WORM MOTHS (Psychidae)

The family Psychidae is widely distributed, but there are few representatives in Britain. The sexes are very different, the males being fairly normal moths, though the wings are only thinly clothed with hairs and scales; but the females are wingless and more or less degenerate. The larvae collect pieces of leaf or other debris to form little cases, which they carry about with them. In many genera, the adult females remain inside these bags and are sought out by the males, who mate with them from outside.

Some of these bag worm moth larvae occasionally desert their host plants and crawl up walls of buildings, sometimes entering rooms. The sight of numerous small creatures moving about in their little cases may cause mild consternation and lead to a call for identification.

The trouble is seldom serious enough to call for drastic control measures.

#### VI · THE CLOVER MITE (*Bryobia praetiosa*)<sup>(21)</sup>

##### (a) Distinctive characters

The clover mite is related to the red spider mite, a common pest of fruit trees. The species *Bryobia praetiosa* belongs to a group of related, very similar, plant feeding mites, some of them being orchard pests. The clover mite, however, is mainly annoying from its habit of invading buildings in large numbers.

The body of the adult mite is about 0·7 to 0·9 mm long and shaped like a pie in a pie-dish (Fig. 52).

##### (b) Life history

Eggs are laid in a dry situation, such as under bark of trees or in crevices in walls or window frames of buildings. The larvae emerge and make their way down to the

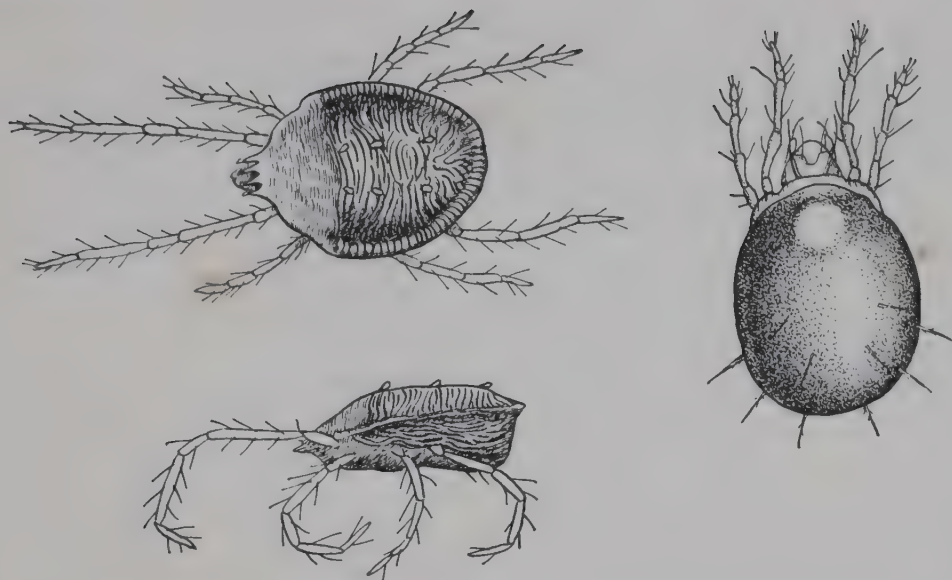


FIG. 52. Garden mites which may invade houses. Left: *Bryobia praetiosa*  $\times 35$  (after Vitzthum, *Acarina*, 1931). Right: *Trichoribates trimaculatus*  $\times 40$  (after Hughes, A. M. *Mites of stored food*, 1961).

grass to feed; but they do not travel far. Subsequently, they return to shelter (often near to the crevice where the eggs were laid) and moult to the first nymphal stage. The nymph wanders down to grass level to feed and finally returns to shelter to moult again. The second nymphal stage repeats this performance and finally the adult female emerges. Males are very rare indeed and most females reproduce parthenogenetically. The females return to the shelter to lay eggs, sometimes more than once. It is thus evident that throughout development there is continual wandering from the crevice shelters down to ground level and back. The eggs tend to be laid amid clusters of cast skins.

### Life cycle

Eggs cease to hatch somewhere between  $7^{\circ}\text{C}$  ( $45^{\circ}\text{F}$ ) and  $2^{\circ}\text{C}$  ( $35^{\circ}\text{F}$ ). There is also an upper limit about  $30^{\circ}\text{C}$  ( $85^{\circ}\text{F}$ ). It appears that the period of maximum activity is late spring, with a dormant period in very hot summers and renewed activity in autumn, when the mites seek shelter for hibernation. (They overwinter in both the egg and adult stage.) Observations on related races, in Europe, suggest that there may be about five generations in a season.

### (c) Importance

There are scattered records of clover mites causing annoyance by entering houses dating back to 1863. The trouble has become much more prevalent, however, with the great increase in house building following the Second World War. The mites are encouraged by planting of lawns in the vicinity of the new buildings.

While the mites are not actually harmful, their invasion of living-rooms in large numbers is very disagreeable and their crushed bodies may stain the walls.

(d) **Control**<sup>(18, 21)</sup>

Since mites do not travel far from their shelters, they can be severely discouraged by removal of a layer of turf from the base of infested walls (or trees). An 18-inch or 2-foot gap should be sufficient, and it need not be left as bare earth as most herbaceous plants do not encourage the mite. The removal of a turf layer should be supplemented by spraying infested walls with an acaricide. Aramite was used successfully in America; malathion in Britain. The latter was used as a 1.5% suspension sprayed on walls at 1 gal/1000 sq ft.

For mites indoors, pyrethrins in an aerosol dispenser make a convenient treatment; but much can be done with a vacuum cleaner.

## VII · BEETLE MITES (Oribatei)

The Oribatei form a large group of the sub-order Sarcoptiformes, comprising many families of free-living mites. In the adult stage, they are characteristically covered by hard, dark armour, which gives rise to the common name. (A typical beetle mite is shown in Fig. 52.) The three nymphal stages have soft leathery integuments and are very sensitive to desiccation. Being restricted to humid environments, they are common in soil, humus and vegetable debris, which they apparently feed on and break down into fine particles. A few species have been found to act as intermediate hosts of anoplocephalid tapeworms (e.g. of sheep).

Normally these mites are harmless and unnoticed; but occasionally they proliferate in vast numbers in vegetation adjacent to houses which the wandering adults may invade. This gives rise to minor concern and requests for identification of these curious little creatures.

Special control measures are seldom necessary, apart from clearing away the vegetable debris which is sheltering the mite population.

## VIII · WOODLICE (Crustacea: Isopoda)

(a) **Historical note**

Thomas Mouffet's *Theatrum Insectorum* contains a section on woodlice, which he calls 'Chisleps', though elsewhere he notes:

The English call them *Sowes*, that is, little Hogs: from the place where they dwell. The Germans call them *Esel*, *Eselgen*, *Holtzwentle*, that is wood-lice, because they are oftentimes found between the Bark and the Tree. [Also:] . . . the chisleps rolls himself up into a little round body. . . . Pliny said not well to call it a centipes, since it hath but 14 feet. . . . It hath two short sailyards, that it may prove its way. . . . It is bred under tyles, water vessels, in the pith of rotting trees, between bark and tree corrupting, also under rocks, growing from moisture putrefying. Then they copulate and . . . lay eggs. . . . From the eggs, first somewhat hard Worms are thrust out, which for some time stick almost immovable, and are white; at length, like their parents, they suck the dew and moisture.

(b) **Distinctive character**

Very few of the enormous class Crustacea have succeeded in colonizing the land. About 35 species of one group, the Isopoda, live on land in Britain and 9 or 10 are

of minor economic importance as horticultural pests. A few genera are quite common and well known; for examples, *Oniscus*, *Porcellio* and *Armadillium* (Fig. 53, c & b). These are known as woodlice in Britain and as pillbugs or sowbugs in U.S.A. Pillbug is a descriptive name for *Porcellio* or *Oniscus* which are able to roll themselves up into a tight, pill-like ball when disturbed.

Three of the more common British species are illustrated in Fig. 53. The genera may be distinguished by the following key.

1. Uropods (terminal appendages) not extending beyond final abdominal segment  
*Armadillium*
- Uropods distinct and projecting at end of abdomen (2)
2. Flagellum of antenna (i.e. portion beyond sharp bend) with 2 segments. Top of head with 2 distinct lateral lobes  
*Porcellio*
- Flagellum of antenna with 3 segments. Top of head without pronounced lobes  
*Oniscus*

### (c) Life history<sup>(12, 23, 27, 38)</sup>

The following details were noted in studies of *Armadillium vulgare*; but other woodlice are not greatly different. The females carry their eggs in a brood pouch until they hatch. From 50 to 150 young have been counted in a single brood. Incubation lasts 50 to 100 days. The first stage young are white, about 2 mm long, and have only 6 pairs of legs. This stage lasts about a day, after which there is a moult to the second stage, also with 6 pairs of legs. The third and subsequent stages, which have 7 pairs of legs, last 2 or 3 weeks each. They begin to reproduce when half-grown (about 7 mm long). The final size attained is about 15 mm in length, after about a year.

In England, there is usually one generation a year; but in France at the latitude of Toulouse, there may be three.



FIG. 53. Isopoda (woodlice). (a) *Oniscus asellus*; (b) *Armadillium vulgare*; (c) *Porcellio scaber*. After Collinge (*J. Bd Agric.* 21, 206). All  $\times 3$ .

**(d) Importance**

These land-living crustacea feed on decaying vegetable or animal matter and occasionally they eat and damage growing plants. They feed mainly at night. During the day they are often found sheltering under boards, flower-pots and so forth in neglected corners of the garden or greenhouse. Sometimes, especially in autumn or winter, they will invade basements or other damp rooms of houses, where their presence is objectionable. This happens when they are present in large numbers in the garden or in a greenhouse or conservatory adjacent to the house.

**(e) Control**

Woodlice which have invaded a room may be simply eradicated by ordinary cleansing measures; they do not, of course, breed indoors. To prevent further invasions, the numbers present in the adjoining garden or greenhouse must be reduced. To do this, all rubbish and such articles as boards, boxes and flower-pots must be cleared up. Then poison traps can be laid by scattering calcium arsenate at the rate of about  $\frac{1}{2}$  oz to 10 sq yd on moist soil and covering with pieces of board or tile. The woodlice which congregate under these covers for shelter will be killed.<sup>(3)</sup>

**C. Outdoor swarms****I. THE SEAWEED FLY (*Coelopa frigida*)<sup>(36, 17)</sup>****(a) Distinctive characters**

Certain genera of flies have adopted the habit of breeding in seaweed cast up on the shore. They include a muscid, *Fucellia*; a borborid, *Thoracochaeta*; and a dryomyzid, *Heleomyza*. But, most prevalent are members of the Coelopidae, especially *Coelopa frigida*. This species breeds along most of the European coastline from Biscay to the Arctic and also in eastern and western America and the Far East at similar latitudes.

**Common species of Coelopidae**

*Coelopa frigida* is dull black or dark brown in colour with a flattened shape giving a 'squashed' appearance. Head and legs are very bristly, but the thorax has long bristles at the sides only. The top of the thorax bears tiny bristles, randomly distributed except for three distinct longitudinal rows. The wings are clear, except for a brownish tinge. Size: very variable (3–11 mm).

*C. pilipes* resembles *C. frigida*; but bristles of head, legs and tip of the abdomen are replaced by a furry pile of fine hairs. *Orygma luctuosa* and *Oedoparea buccata* are much less bristly, and the latter is mainly orange in colour. *Malacomyia scio-myzina* is less than 4 mm long, has a yellow head and legs and is not outstandingly bristly.

**(b) Life history<sup>(9, 16)</sup>**

Females lay batches of about 80 eggs. In laboratory culture, 3 to 5 batches are produced. Eggs are laid among rotting seaweed, especially heaps of *Laminaria* or *Fucus*.

The larvae which emerge resemble fly maggots; they feed on the slimy decomposition products of the weed. The larvae are never found in the drier surface layer of wrack, but always a few inches down in the moist, decomposing and sometimes pulp-like mass below. It is notable that the larvae are either present in very large numbers (over 600 have been found per litre) or they are absent altogether; they do not survive at all well in small numbers. The most prolific sites are large banks of wrack, often formed at the foot of cliffs or boulders, where it piles up because it cannot be scattered or pushed farther back. Narrow 'strings' of wrack along the tide mark tend to dry up and do not decompose so well. There are three larval stages and the pupae are formed in clusters, in the puparia characteristic of the higher flies.

The adult flies keep close to the surface of the seaweed in cold winter conditions; in warmer weather they may fly about in columns a foot or two above the surface. Sometimes they travel away from the shore and, on occasions, can travel long distances inland; but they probably do not breed anywhere except in rotting seaweed.

Adults of *C. frigida* have the curious character of being very readily attracted by the odours of trichlorethylene or carbon tetrachloride; this is not shown by other coelopids, except perhaps *Malacomyia*.

*Speed of development.* An old record of natural development gives a total of about 6 weeks (E, 2.5; L, 28; P, 14). Under laboratory conditions, at 25°C, development takes 12 days.

*Seasonal abundance.* Seaweed flies tend to be most numerous in mild autumns. During the summer, less wrack is thrown up and decomposition is too rapid. During very cold winters the development is retarded and the adults do not fly far from the seaweed.

### (c) Prevalence and importance<sup>(36, 17)</sup>

In most years, seaweed flies are no more than a very minor nuisance; but occasionally, circumstances lead to excessive breeding. The causes responsible probably include excessive accumulations of seaweed during a long mild autumn. Severe outbreaks along the south coast were experienced in 1950. In this season, the flies penetrated inland as far as London (some were even taken in Oxford).

Large clouds of flies tend to annoy visitors at seaside resorts, which is bad for the tourist trade. Apart from being a nuisance on the beaches by day, the flies are attracted by the lights of cafés and places of amusement by night. Also, they have the curious habit of congregating in vast numbers at dry-cleaning establishments and garages, which make use of trichlorethylene, causing surprise and some consternation.

### (d) Control<sup>(17)</sup>

The most efficient and simplest method of preventing a seaweed fly nuisance is to destroy the breeding ground. This can be accomplished by pushing the piles of seaweed down below high-water mark, so that the sea will disperse them. (Small bulldozers may be necessary for this task.) The larvae will be either eaten by birds or drowned, after being washed from the wrack by the incoming tide.

II · ST MARK'S FLIES; FEVER FLIES (Bibionidae)<sup>(13, 15)</sup>

Flies of this family are mainly black, hairy flies, fairly robust, the females of some species having clouded wings. Those of the male are clear, except for a dark mark on the front edge; in both sexes the hinder wing veins tend to be atrophied. The antennae are many-jointed (Nematocera) but quite short and arise from in front of the eyes, just above the mouth.

Two common species are: *Dilophus febrilis* (sometimes called, without justification, the fever fly) and *Bibio marci* (St Mark's fly, probably because it often begins to emerge on St Mark's Day, 25 April).

*D. febrilis* is about 6 mm long and can be distinguished by a circlet of spines on the tip of each fore tibia and by a double collar of spines on the front part of the thorax. *B. marci* is 10–12 mm long, the biggest British bibionid. It has a single large spine on each front tibia.

Large numbers of bibionids swarm in some rural districts in early spring. The females mainly crawl over grass stems and other vegetation, while the males hover, rather sluggishly, overhead. Apart from the minor annoyance caused by the adult swarms, they are believed to be beneficial in pollenating fruit trees. The larvae, however, live in the earth, feeding on plant roots, and are sometimes agricultural pests.

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# 17· *Biological appendix*

## LISTS AND KEYS

### Classification of insects

The following list of insect orders, with sub-divisions down to families, is given for reference; it includes only the families containing species mentioned in the text. Normally, only generic and specific names are italicized; but in this list, the families are printed in italics. The classification is based on that given in Imms, *Textbook of Entomology* (9th ed., revised by Richards and Davies, 1957).

#### Sub-class: APTERYGOTA

THYSANURA (Bristletails)  
COLLEMBOLA (Springtails)

#### Sub-class: PTERYGOTA. Division: EXOPTERYGOTA

ORTHOPTERA	<i>Gryllidae</i> (Crickets)
DICTYOPTERA	<i>Blattidae</i> (Cockroaches)
DERMAPTERA (Earwigs)	
MALLOPHAGA (Biting lice)	
SIPHUNCULATA (Sucking lice)	
HEMIPTERA	<i>Cimicidae</i> (Bed bugs)

#### Sub-class: PTERYGOTA. Division: ENDOPTERYGOTA

LEPIDOPTERA (Moths & Butterflies)	
Tineoidea	<i>Tineidae</i> <i>Oecophoridae</i> <i>Gelechiidae</i>
Pyralidoidea	<i>Pyralidae</i> <i>Galeriidae</i> <i>Phycitidae</i>
COLEOPTERA (Beetles)	
Adephaga	<i>Carabidae</i> (Ground beetles)
Polyphaga	
Dermestoidea	<i>Dermestidae</i> (Hide beetles)
Bostrychoidea	<i>Bostrychidae</i> <i>Anobiidae</i> <i>Lyctidae</i> (Powder post beetles) <i>Ptinidae</i> (Spider beetles)
Cleroidea	<i>Cleridae</i> <i>Trogositidae</i>

Cucujoidea

- Cucujidae*
- Silvanidae*
- Nitidulidae*
- Cryptophagidae*
- Lathridiidae*
- Mycetophagidae*
- Tenebrionidae*
- Oedemeridae*
- Bruchidae* (Pulse beetles)
- Cerambycidae* (Longhorn beetles)
- Anthribidae*
- Curculionidae* (Weevils)

Chrysomeloidea

Curculionoidea

HYMENOPTERA

- Formicoidea (Ants)
- Apoidea (Bees)
- Vespoidea (Wasps)
- Ichneumonoidea (Parasitic wasps)

DIPTERA

**Nematocera**

- Dixidae* (Dixa midges)
- Psychodidae* (Moth flies)
- Culicidae* (Mosquitoes)
- Anisopodidae*
- Bibionidae*
- Simuliidae* (Blackflies)
- Chironomidae* (non-biting midges)
- Ceratopogonidae* (Biting midges)
- Tabanidae* (Horseflies)
- Phoridae*
- Piophilidae*
- Coelopidae* (Seaweed flies)
- Drosophilidae* (Fruit flies)
- Chloropidae*
- Muscidae* (Houseflies etc.)
- Calliphoridae* (Blowflies)
- Hippoboscidae*
- Pulicidae*
- Ceratophyllidae*
- Leptopsyllidae*

**Brachycera**

**Cyclorrhapha**

**Pupipara**

SIPHONAPTERA (Fleas)

**The Keys**

The following keys for identification of domestic insect pests may be found more or less useful by different types of reader. It was considered desirable to remove all long and involved keys from the general text. Some of the groups identified in the following keys can be further separated by *short* keys in the relevant chapters. Some of these short keys are very important (e.g. to distinguish the various cockroaches or

ants); others are of minor importance (e.g. to distinguish common species of some genera of stored product beetle pests). The keys are arranged as follows:

*Group 1 (see Chapter 2) ORDERS*

Elementary keys to distinguish the principal orders likely to occur as domestic and medical pests in Britain.

- 1a Key to adults and nymphs
- 1b Key to larvae
- 1c Key to pupae

*Group 2 (see Chapters 8 and 9) Diptera*

Key to species of houseflies, blowflies and biting flies other than culicidae.

- 2a Key to adults
- 2b Key to larvae (especially those liable to cause myiasis)

*Group 3 (see Chapter 9) Culicidae*

Keys to branches of the family Culicidae

- 3a Sub-families, by adults
- 3b Sub-families, by larvae

*Group 4 (see Chapter 9) Culicinae*

Keys to genera and species of common British mosquitoes.

- 4a Genera, by adults
- 4b Species, by adults
- 4c Genera, by larvae

*Group 5 (see Chapter 10) Aphaniptera*

Key to common genera of British fleas.

*Group 6 (see Chapters 11 and 13) Lepidoptera*

Keys to moths commonly occurring as pests of stored foods and woollen textiles.

- 6a Key to adults (pests of food and fabrics)
- 6b Key to larvae (food pests)
- 6c Key to larvae (fabric pests)

*Group 7 (see Chapters 11, 13 and 14) Coleoptera*

Key to genera and species of beetles commonly occurring as pests of stored food, fabrics and wood.

- 7a Key to adults.
- 7b Key to larvae of certain Dermestidae.
- 7c Key to larvae of wood-boring beetles.

# Key 1a

Key to principal orders by characters of nymphs and adults

1. One or two pairs of wings present (9)  
No wings visible (i.e. either *Apterygota*, or young nymphs or degenerate groups) (2)
2. Tip of abdomen bearing springing organ. Small, delicate insects with 6-segmented abdomen *Collembola*  
Tip of abdomen bearing cerci (3)  
Tip of abdomen without special appendages (4)
3. Cerci thread-like, often with similar thread-like tail between them. Small delicate carrot-shaped insects. *Thysanura*  
Cerci forcep-like, typical 'earwig' shape *Dermaptera*  
Cerci variable. Usually robust insects with spined legs *Dictyoptera* (*Blattidae*)
4. Small insects (less than a  $\frac{1}{4}$  inch) with rather soft pale (yellowish) cuticles (5)  
Larger insects or with fairly hard dark (brown) cuticles (6)
5. Antennae short, never more than 5 segments. Parasitic on warm-blooded animals  
Biting mouthparts *Mallophaga*  
Sucking mouthparts (withdrawn inside head) *Siphunculata*  
Antennae with more than 9 (usually 13-50) segments. Not parasitic *Psocoptera*
6. Mouthparts adapted for biting (tooth-like mandibles) (7)  
Mouthparts adapted for piercing and sucking (8)
7. Pronounced waist between thorax and abdomen. Antennae 'elbowed'. Ant-like *Hymenoptera* (*Formicidae*)
8. Antennae short and stout lying in groove. Body laterally compressed. Flea-like *Siphonaptera*  
Antennae slender. Bug-like *Hemiptera* (*Cimicidae*)
9. One pair of wings only. Hind pair reduced to small rods *Diptera*  
Two pairs of wings present (10)
10. Wings similar in texture (11)  
Front wings stiffer (usually leathery or horny) than hind pair and covering them when at rest (12)
11. Wings opaque, covered with minute scales *Lepidoptera*  
Wings transparent, hind pair linked to front ones by tiny hooks *Hymenoptera*
12. Front wings horny or leathery, devoid of 'veins' (13)  
Front wings leathery, showing some 'veins' (14)
3. Front wings always very short. Forcep-like cerci present on abdomen *Dermaptera*  
Front wings usually completely covering abdomen. No cerci present *Coleoptera*

14. Biting mouthparts (15)  
 Piercing mouthparts carried in rostrum pointing backwards under head  
*Hemiptera*
15. Hind legs enlarged and adapted for jumping  
 All legs similar  
*Orthoptera*  
*Dictyoptera* (Blattidae)

### Key 1b

#### *Key to principal orders by larval characters*

1. Thoracic legs present (2)  
 No thoracic legs (4)
2. 'Prolegs' absent from abdomen (simple larva or grub type) *Coleoptera*  
 'Prolegs' present on abdomen (caterpillar type) (3)
3. Five pairs of 'prolegs' (or less), the first pair on the 3rd or subsequent segment of the abdomen *Lepidoptera*  
 Six to eight pairs of 'prolegs', the first pair on the 2nd abdominal segment  
*Hymenoptera* (Sawflies)
4. Head distinct (grub type) (5)  
 Head reduced, capable of retraction into thorax (maggot type) (7)
5. Abdominal spiracles all similar (6)  
 Last pair of abdominal spiracles larger than the rest, often borne on long air tubes. Head moderately armoured, similar in colour to body *Diptera*
6. Head darker in colour than body and well armoured. Sluggish larvae  
*Coleoptera*  
 Head similar in colour to body (whitish). Small active larvae, with thrusting processes at tip of abdomen *Aphaniptera*
7. Usually several abdominal spiracles present. Opposite mandibles present. Found in little cells of earth, paper or wax constructed by parents. Often communal insects *Hymenoptera*  
 Usually only one pair of large spiracles situate at tip of abdomen. Mouthparts reduced to non-opposable vertical black hooks. Found in decaying organic matter *Diptera*

### Key 1c

#### *Key to main orders by pupal characters*

1. Pupa inside a brown puparium formed of the last larval skin. Pupa with one pair of wing rudiments *Higher Diptera*  
 No puparium. Pupa either free or inside a cocoon (2)
2. Limbs glued to the body *Lepidoptera* (almost all)  
 Limbs free (3)
3. No wing buds (4)  
 Wing buds present (5)

4. Wasp-waist evident. Pupae in cells in colonies (ant-hills) *Hymenoptera*  
(part) (ants)  
No wasp-waist. Pupae in small irregular cocoons incorporating rubbish *Siphonaptera*  
*Diptera* (part)  
5. One pair of wing buds only (6)  
Two pairs of wing buds  
6. Front (upper) pair unveined (future elytra) *Coleoptera*  
Front (upper) pair usually much larger than hind pair. Veined. Wasp-waist  
often present *Hymenoptera* (part)

### Key 2a

#### *Key to adult flies of medical or domestic importance in Britain*

This key only includes a very restricted selection of Diptera and can only be used to assist in identification of (a) flies liable to occur inside houses; (b) bloodsucking flies and others which may sometimes be confused with them.

1. Abnormal, flattened flies, with legs projecting laterally, giving a crab-like appearance. All bloodsucking parasites of animals. (Some wingless, or with stunted wings) (Fig. 21*d, e*) *Pupipara*  
Normal flies, gnats, etc. (2)
2. Antennae with at least 8, nearly similar segments *Nematocera* (4)  
Antennae with less than 6 similar segments (3)
3. Large, robust flies, with the eyes banded or spotted in life. Bare not bristly, often with a pattern on body or wings or both *Tabanidae*  
(Horseflies; clegs)  
Small flies; or if large and robust, then very bristly (10)
4. Back of the thorax bearing a prominent V-shaped groove. Usually rather large with long legs *Tipulidae* (Daddy longlegs)  
Without V-shaped groove (5)
5. Ocelli present. Moderate-sized (7 mm long) gnat-like flies with mottled wings (Fig. 15*a*) *Anisopus* (Window gnat)  
Ocelli absent (6)
6. Costal vein (along anterior edge of wing) running round beyond tip of the wing. Scales or hairs often present on the wing (7)  
Costal vein ending before the tip of the wing which does not bear hairs or scales (8)
7. Wings almond-shaped, hairy, carried at a roof-like angle in repose (Fig. 15*b*) *Psychodidae* (Moth flies)  
Wings oblong with rounded tip, usually bearing scales, carried flat on top of each other in repose *Culicidae* (Mosquitoes)  
(see pp. 189–190)
8. Antennae shorter than the thorax, consisting of closely-set ring-like segments never plumose. Body thick-set with legs strong, not long and thin (Fig. 20*a*) *Simuliidae* (Blackflies)

- Antennae longer than the thorax and usually hairy or bushy (9)
9. Back of the thorax with a longitudinal groove. Legs thin, forelegs often especially long. Mouthparts incapable of bloodsucking (Fig. 20c) *Chironomidae*  
 Back of the thorax without a longitudinal groove. Mouthparts capable of bloodsucking. Mostly minute insects with dappled wings (Fig. 20b) *Ceratopogonidae*
10. Rather large robust flies or with distinct metallic green or blue coloration. (Mainly 10 mm long or more with a wing-span of 18 mm or more) *Calliphoridae* (Blowflies) (11)  
 Moderate-sized flies (mostly 5–8 mm long with a wing-span about 10–18 mm) rather similar to the common housefly in appearance (14)  
 Very small flies (not more than 4 mm long with 8 mm wing-span) (17)
11. Large hairy fly, with thorax bearing longitudinal black and grey strips; abdomen chequered grey and black. (Length about 13 mm; wing-span about 22 mm) (Fig. 14c) *Sarcophaga*  
 Thorax and abdomen more uniform. Bluish or green metallic tinge (12)
12. Highly metallic greenish-blue or greenish-yellow flies (Fig. 14e) *Lucilia*  
 (*Dasyphora cyanella* is similar, but has two longitudinal marks on the back of the thorax.)  
 Blue-grey or blue-black flies not highly metallic (13)
13. Blue with much grey dusting overlying the blue. Flies producing loud buzzing sound in flight (Fig. 14a) *Calliphora*  
 (Bluebottles)  
 Midnight blue, almost black blowflies, smaller than the common bluebottles *Phormia*
14. Piercing mouthparts in the form of a forward-projecting proboscis visible from above (Fig. 22c). Fly rather resembling an ordinary housefly in other respects (Fig. 14h) *Stomoxys calcitrans*  
 (Stable fly)  
 Sucking proboscis not projecting in front of head (15)
15. Fourth wing vein very sharply bent forward so that it nearly joins the third near the wing edge (16)  
 Fourth wing vein gently curving forward. Legs partly brown; tip of scutellum reddish (about 8 mm long with 16 mm wingspan) (Fig. 14g) *Muscina stabulans*  
 Fourth wing vein parallel to or diverging from the third. Small flies (about 6 mm long with 12 mm wing-span) (Fig. 14d) probably *Fannia*
16. Wings carried flat one over the other on the back when at rest. Thorax bearing golden-yellow bristles (Fig. 14f) *Pollenia rudis* (Cluster fly)  
 Wings carried at a diverging angle when at rest. Thoracic bristles black (Fig. 14b) *Musca*
17. Very small flies (about 2 mm long with 5 mm wing-span). Yellowish or brownish in colour (18)  
 Shining black flies, rather larger than above (19)

18. Bristle on the antenna feathered. Attracted by ripe fruit, etc. (Fig. 15e, f, g)  
*Drosophila* (Fruit flies)  
 (*D. funebris* has the back of the thorax a shining reddish brown; while *D. repleta* has a dull grey-brown thorax with each bristle arising from a darker spot on it.)  
 Bristle on antenna plain. Lemon-yellow flies with black markings. Sometimes hibernate indoors in large numbers (Fig. 15c) *Thaumatomyia notata*
19. Anterior veins of wing much thicker than others. (Rarely seen; but larvae and pupae occur in milk curds) (Fig. 15h) *Phoridae*  
 Anterior waist between thorax and abdomen. Wings often with a black spot at tip *Septis*  
 More robust, without pronounced waist. (Larvae in cheese or bacon) (Fig. 15d) *Piophil*

### Key 2b

*Key to larvae of Diptera liable to cause myiasis (after Smart)*

1. Larvae with a distinct head (2)  
 Headless maggots (3)
2. Nearly cylindrical, naked (Fig. 16a) *Anisopus*  
 Spindle-shaped, body surface bearing hairs (Fig. 16b) *Psychoda*
3. Somewhat flattened, bearing projecting tail-like processes on the dorsal side (4)  
 Without tail-like processes on dorsal side (5)
4. Processes simple (Fig. 16d) *Fannia canicularis*  
 Processes pinnate (Fig. 16d) *Fannia scalaris*
5. Small maggots, not exceeding 10 mm in length when fully grown; body rather cylindrical with the thickest part about the middle; posterior end not truncate; posterior spiracles small and raised above the general surface (*Acalypterates*) (6)  
 Larger maggots up to 18 mm in length; body definitely tapering from behind forward, the thickest part being just before the sharply truncate hind end; posterior spiracles flush with the surface or sunk in a fold not obviously small (*Calypterates*) (7)
6. Stouter larvae; posterior spiracles raised on 2 flask-like papillae which are fused together basally; ventro-lateral processes small, rather flap-like (Fig. 16i) *Drosophila*  
 Thinner larvae; posterior spiracles raised on 2 cones; ventrolateral projections finger-like *Sepsis*  
 Thinner larvae; posterior spiracles raised on 2 cones on the dorsal surface of which there is a small vertical papilla; ventro-lateral processes tapering and slightly curved upward; in life, the mature larvae jump about actively (Fig. 16e) *Piophila casei*

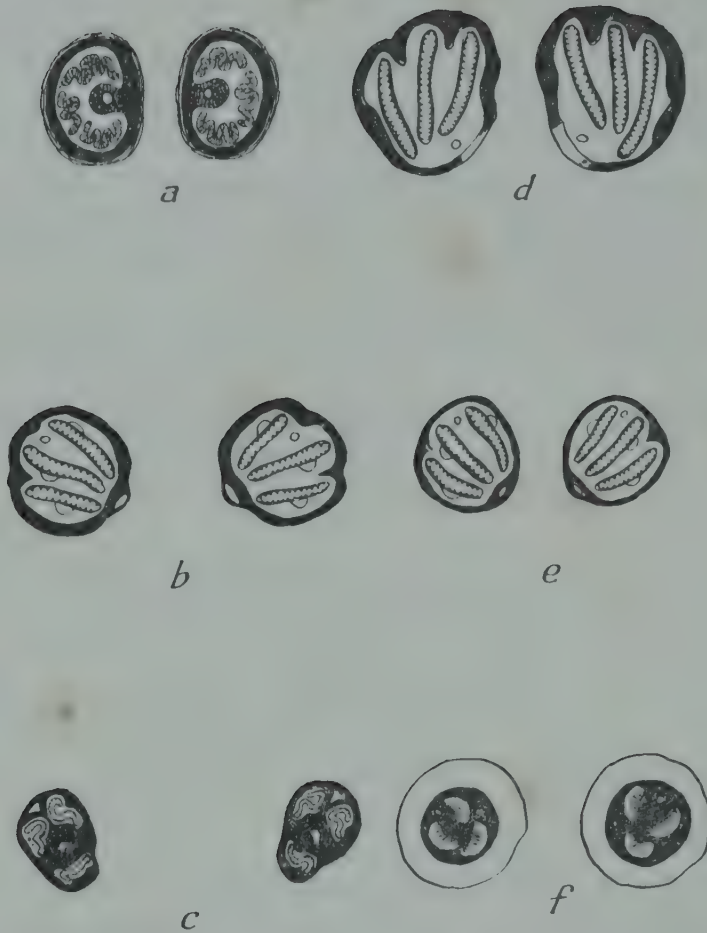


FIG. 54. Spiracles of larvae of certain Muscidae and Caliphoridae. (a) *Musca domestica*; (b) *Calliphora erythrocephala*; (c) *Stomoxys calcitrans*; (d) *Sarcophaga* sp.; (e) *Lucilia sericata*; (f) *Muscina stabulans*. Not all to same scale. After Smart (loc. cit.).

7. Posterior spiracles sunken and often completely hidden by the overlapping of the short fleshy processes that surround the truncated area bearing the spiracles; the slits in the spiracles nearly vertical (Fig. 54d) *Sarcophaga*  
 Posterior spiracles not so sunken; slits on the spiracles straight but not vertical *Calliphora* or *Lucilia*  
 (Differences shown in Fig. 54)  
 Posterior spiracles not sunken; slits bent or sinuous *Musca domestica*,  
*Stomoxys calcitrans* or *Muscina stabulans*  
 (Differences shown in Fig. 54)

### Keys to branches of the Family Culicidae (after Smart)

#### Key 3a · Adults

1. No scales on the wings (though small hairs may be present). Wing venation similar to Fig. 20d. Mouthparts small, unfitted for bloodsucking (*Dixinae*)  
 Scales at least on hind border of wing (2)

2. Few if any scales on the wing (i.e. hind margin only). Mouthparts small, unfitted for piercing (Chaoborinae)
- Scales on wing as well as along hind margin. Mouthparts long and, in female, adapted for piercing (Culicinae) (Mosquitoes)

### Key 3b · Larvae

1. Thorax narrow, distinctly segmented (Fig. 20d) (Dixinae)
- Thorax markedly broader than abdomen without distinct segmentation (2)
2. Antennae prehensile with long and strong apical spines. No bushy 'mouth brush' (Chaoborinae)
- Antennae not prehensile. Mouth brush present Culicinae (Mosquitoes)

## Key to British genera and species of mosquito, based on adult female characters (after Edwards, Oldroyd and Smart)

### Key 4a · Genera

1. Palpi as long as proboscis (Fig. 17). Abdomen without scales Anopheles
- Palpi shorter than proboscis (Fig. 17). Abdomen with scales (2)
2. Abdomen long-tapering and pointed. Claws on fore and mid feet toothed Aedes
- Abdomen slightly tapering and blunt. Claws all simple (3)
3. Tarsi without pale rings Culex
- Tarsi with pale rings (4)
4. White rings on 5th tarsal segments of all legs and median band on first tarsal segments. Wings never spotted Taeniorhynchus
- Either white rings on 5th tarsal segments or median band on 1st tarsal segments (never both). Common species with spotted wings Theobaldia

### Key 4b · Species

(Relatively rare or unimportant forms are given in brackets)

#### ANOPHELES

1. Wings spotted (Fig. 18a) An. maculipennis
- Wings unspotted (2)
2. Head with a frontal tuft of white scales (3)
- Head without a frontal tuft of white scales (An. algeriensis)
3. Body brown (Fig. 18c) An. claviger
- Body black (Fig. 18b) An. plumbeus

#### AEDES

1. Pale rings on the tarsi (2)
- No pale rings on the tarsi (7)
2. Rings extending on both sides of the joints (3)
- Rings confined to the base of each segment (4)

3. Thorax fawn-coloured with 2 narrow white lines (Fig. 19b) *A. caspius*  
 Thorax with broad dark brown stripe, on each side of which is a broad ashy-white area (*A. dorsalis*)
4. Abdomen mainly yellow, unbanded (*A. flavescens*)  
 Abdomen distinctly banded (5)
5. Thorax yellowish towards sides above *A. annulipes*  
 Thorax darker (6)
6. Pale bands of abdomen of uniform width (Fig. 19a) *A. cantans*  
 Pale bands of abdomen constricted in middle (*A. vexans*)
7. Abdomen unbanded (8)  
 Abdomen with transverse, pale bands (9)
8. Thorax ornate, knees silvery (Fig. 19f) *A. geniculatus*  
 Thorax reddish brown, knees dark *A. cinereus*
9. Abdomen with a tendency to have a median longitudinal pale stripe, at least towards the tip (Fig. 19e) *A. rusticus*  
 Abdomen without trace of such a stripe (10)
10. Abdominal bands (at least the last few) narrowed in the middle, their posterior margins  $\Lambda$ -shaped (Fig. 19d) *A. punctor*  
 Abdominal bands not narrowed in middle (11)
11. Fore- and mid-femora conspicuously sprinkled with pale scales in front (12)  
 Fore- and mid-femora with only a few pale scales in front (13)
12. Dark parts of abdomen with scattered pale scales (Fig. 19c) *A. detritus*  
 Dark parts of abdomen without scattered pale scales (*A. leucomelas*)
13. Hind tibia with a white stripe on outer side (*A. stictus*)  
 Hind tibia without such a stripe (*A. communis*)

## CULEX

(N.B. the two forms given as species below are very closely related and often given as races of *C. pipiens*. They are difficult to distinguish, but their habits are distinct.)

Dorsal abdominal pale stripes constricted laterally, and sometimes centrally so as to appear convex or bilobed. Patches of dark scales on pale underside of abdomen (Fig. 18d) *C. pipiens*

Dorsal abdominal pale stripes parallel unconstricted. Dark scales rare or absent in centres of ventral abdominal segments *C. molestus*

## MANSONIA

Only British species (Fig. 18f)

*M. richiardii*

## CULISETA

1. Wings with small dark spots; large species (2)  
 Wings without dark spots (4)
2. Pale rings near the tip of each femur and in middle of 1st segment of tarsus of each leg (3)  
 Such rings absent (*C. alaskaensis*)

3. Abdomen with conspicuous white bands (Fig. 18e)  
Abdomen not distinctly banded, suffused with yellow

4. Proboscis all dark  
Proboscis pale in middle
- C. annulata*  
(*C. sub-ochroea*)  
(*C. morsitans*)  
(5)

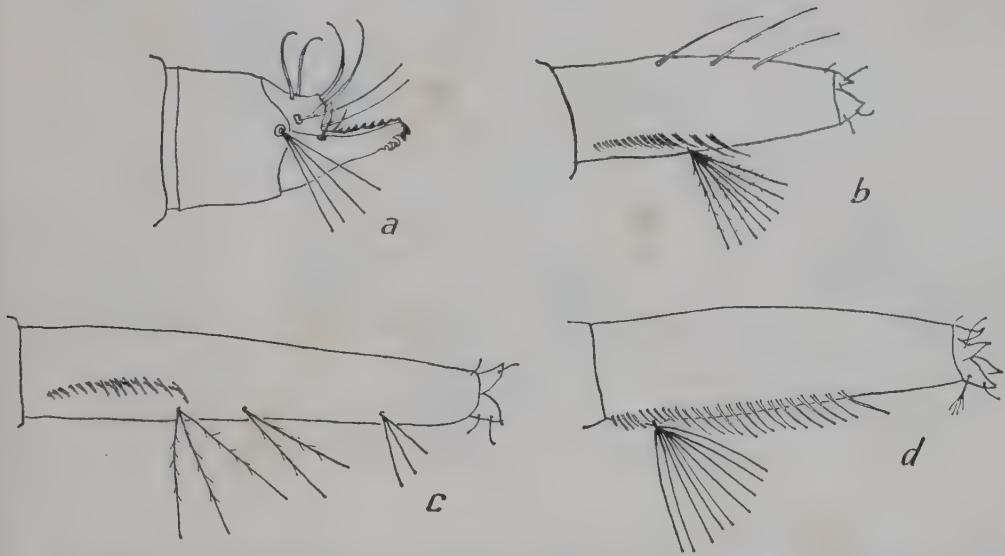


FIG. 55. Siphons of larvae of British culicine mosquitoes. (a) *Mansonia richiardii*; (b) *Aedes rusticus*; (c) *Culex pipiens*; (d) *Culiseta annulata*. After Marshall (loc. cit.).

5. Yellowish rings at all tarsal joints  
Rings at last 2 tarsal joints of hind legs inconspicuous or absent

(*C. fumipennis*)  
(*C. litorea*)

Key 4c

Key to British genera of mosquitoes based on characters of older larvae (after Marshall)

1. Siphon modified for piercing submerged stems of aquatic plants (Fig. 55a)  
Siphon normal in shape

2. Siphon with 4 (occasionally 3 or 5) hair tufts (Fig. 55c)  
Siphon with only 1 hair tuft

3. Hair tuft near centre of siphon (Fig. 55b)  
Hair tuft near base of siphon (Fig. 55d)
- Mansonia*  
(2)  
*Culex*  
(3)  
*Aedes*  
*Culiseta*

Key 5

The following is a simple key for distinguishing flea genera likely to be found inside houses in Britain. (The differential characters will be found in Fig. 56)

1. Neither oral nor thoracic combs present  
Thoracic comb present; genal combs absent  
Both thoracic and genal combs present

2. Row of bristles along back of the head  
Only one bristle (on each side) at the back of the head
- (2)  
(3)  
(4)  
*Xenopsylla*  
*Pulex*

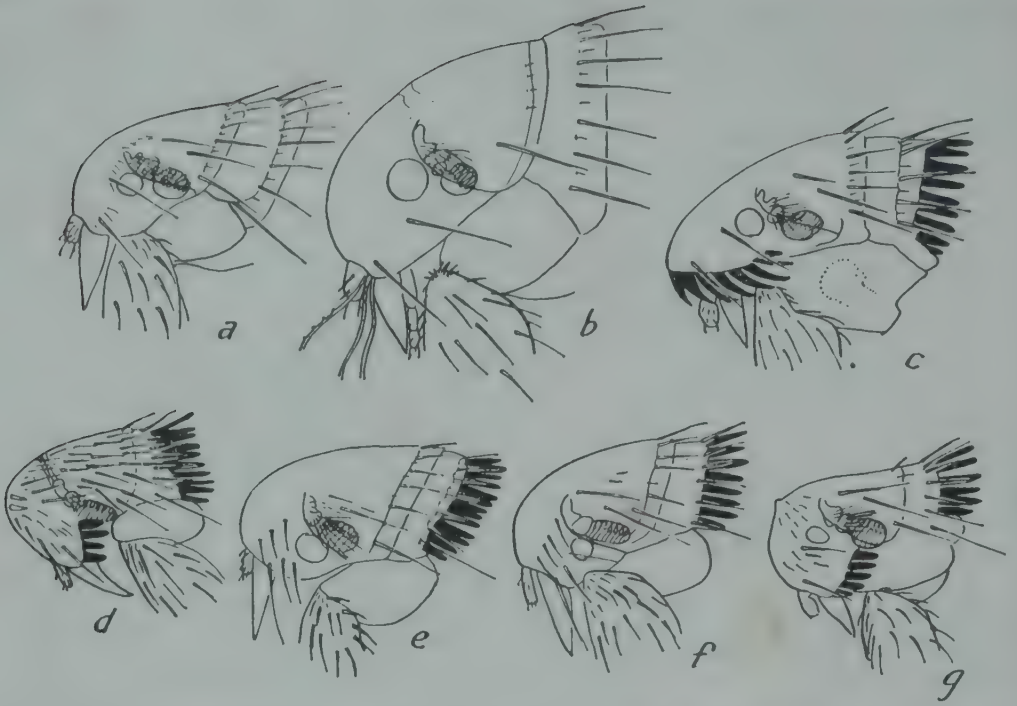


FIG. 56. Heads of British fleas. (a) *Xenopsylla cheopis*; (b) *Pulex irritans*; (c) *Ctenocephalides felis*; (d) *Leptopsylla segnis*; (e) *Ceratophyllus gallinae*; (f) *Nosopsyllus fasciatus*; (g) *Spilopsyllus cuniculi*. All females except (g). After Smart (loc. cit.).

- |   |                        |
|---|------------------------|
| 3. Thoracic comb with more than 24 teeth              | <i>Ceratophyllus</i>   |
| Thoracic comb with fewer than 24 teeth                | <i>Nosopsyllus</i>     |
| 4. Eye absent   | <i>Leptopsylla</i>     |
| Eye present   | (5)                    |
| 5. Genal comb of 5 rounded spines arranged vertically | <i>Spilopsyllus</i>    |
| Genal comb of 8 sharp spines arranged horizontally    | <i>Ctenocephalides</i> |

(Note: Of these genera *Pulex*, *Xenopsylla*, *Ctenocephalides* and *Spilopsyllus* belong to the family Pulicidae; *Ceratophyllus* and *Nosopsyllus* belong to the family Ceratophyllidae; and *Leptopsylla* belongs to the family Leptopsyllidae.)

### Key 6a

Key to adults of common lepidopterous pests of stored food (from Hinton and Corbet)  
N.B. The various wing patterns are shown in Fig. 57

1. Hindwing with fringe short, the hairs not nearly half the breadth of the wing  
*Pyralidina* (2)
- Hindwing with fringe long, the hairs at least as long as half the breadth of the wing  
*Tinaeina* (8)
2. Labial palps prominent and curved upwards (3)
- Labial palps inconspicuous in males of *Corcyra cephalonica* and *Paralipsa gularis* but conspicuous in remainder, where they are straight in front of the head or slightly curved downwards (6)

3. Uppersides forewing pale ochreous buff, with basal and apical areas purple-brown, the pale centres divided from the darker areas by narrow white lines. Uppersides hindwing smoky-black, crossed by 2 narrow whitish lines

*Pyralis farinalis*

(The 'meal moth')

Uppersides forewing dull greyish brown with markings obscure; 2 bands (light or dark) can be distinguished across the wing.

Uppersides hindwing greyish white or greyish buff and unmarked (4)

(N.B. The three following species have rather similar wing patterns and are difficult or impossible to distinguish in rubbed specimens.)

4. Uppersides forewing with the outer band well defined, rather sinuate, pale and bordered on each side by a narrow dark line, the dark bordering being more intense anteriorly

*Ephestia elutella*

(The 'warehouse' moth')

Uppersides with the outer band very obscure and not well defined (5)

5. Upperside forewing with the inner band dark and straight (at right angles to front margin), rather broad and continuous and with a broad pale band along its inner edge

*Cadra cautella*

(The 'tropical warehouse moth')

Upperside forewing with the inner band oblique, rather irregular and consisting of dark streaks or spots, and without a pale band along its inner edge

*Anagasta kuhniella*

(The 'Mediterranean flour moth')

6. Upperside forewing with the basal third pale yellowish buff, this pale area separated from the outer reddish-brown area by a dark-brown line. Head without a projecting tuft of scales

*Plodia interpunctella*

('Indian-meal moth')

Upperside forewing uniformly coloured pale buff-brown. Head with a projecting tuft of scales. Labial palps inconspicuous in males, long and prominent in females (7)

7. Upperside forewing without spots but with the veins slightly darkened.

Upperside hindwing darker in male than in female *Corcyra cephalonica*

Upperside forewing with a black spot at or beyond the centre of the wing.

Male has a reddish-yellow streak in centre of forewing, absent in female

*Paralipsa gularis*

8. Labial palps long, sickle-shaped, sharply pointed and curved upwards. Head smooth (9)

Labial palps shorter, rather blunt, straight or nearly straight, projecting in front of the head or sloping downwards. Head roughly haired (11)

9. Hindwing apex very elongated, sharply pointed and needle-like. Upperside forewing pale ochreous buff and, usually, a black dot can be seen beyond centre of the wing; upperside hindwing with a whitish stripe, running from wing base to beyond centre for about  $\frac{2}{3}$  the length of the wing

*Sitotroga cerealella*

(The 'Angoumois grain moth')



FIG. 57. Wings of moths which attack stored food or fabrics. (a) *Trichophaga tapetzella*; (b) *Sitotroga cerealella* (female); (c) the same (male); (d) *Plodia interpunctella*; (e) *Paralipsa gularis* (female); (f) *Cadra cautella*; (g) *Hofmannophila pseudospretella*; (h) *Nemapogon granella*; (i) *Anagasta kuhniella*; (j) *Tineola bisselliella*; (k) *Pyralis farinalis*; (l) *Ephestia elutella*; (m) *Tinea pellionella*; (n) *Corcyra cephalonica* (female); (o) *Endrosis sarcitrella*. (All  $\times 3$  approximately.) After Hinton and Corbet (B.M. (Nat. Hist.) Econ. Series No. 15).

- Hindwing apex may be pointed but not needle-like. Upperside hindwing without yellowish stripe (10)
10. Head and at least the front of thorax conspicuously white. Upperside forewing shining buff, speckled with dark brown and usually 2 or 3 blackish spots  
*Endrosis sarcitrella*  
(The 'white shouldered house moth')
- Head and thorax brown, upperside forewing buff-brown to dark buff-brown, with 3 more or less distinct brown spots  
*Hofmannophila* (= *Borkhausenia*) *pseudospretella*  
(The 'brown house moth')
11. Upperside forewing with the basal third deep chocolate brown, contrasting sharply with the whitish outer two-thirds, and with wing apex slightly darkened  
*Trichophaga tapetzella*  
(The 'tapestry moth')
- Upperside forewing more or less uniformly coloured (12)
12. Upperside forewing pale ochreous buff, entirely unmarked and without dark dusting  
*Tineola bisselliella*  
(The 'common clothes moth')
- Upper side forewing with dark markings and some dark dusting (13)
13. Upperside forewing with a prominent chain of dark reddish-brown conjoined spots, running obliquely across centre of wing; ground colour buff with dark dusting and other irregular dark-brown markings  
*Tinea granella*  
(The 'corn moth')
- Upperside forewing uniformly pale shining buff or brown with only 3 faint, dark spots; dark dusting very slight  
*Tinea pellionella*  
(The 'case-bearing clothes moth')

Key 6b

Key for the separation of the more common lepidopterous larvae infesting stored products

The nomenclature used here for the setae of the thorax and abdomen is that elaborated by Fracker and used by Hinton. It is illustrated in Fig. 58. Each seta is indicated by a Greek letter, as follows:

$\alpha$ ALPHA	$\eta$ ETA	$\pi$ PI
$\beta$ BETA	$\theta$ THETA	$\rho$ RHO
$\gamma$ GAMMA	$\kappa$ KAPPA	$\sigma$ SIGMA
$\delta$ DELTA	$\mu$ MU	$\tau$ TAU
$\epsilon$ EPSILON	$\nu$ NU	

Not all of these setae are required for the purposes of the abridged key given below, but they are included in the diagram for completeness. Some of the setae are always associated with others in definite groups, thus: KAPPA group ( $\theta + \kappa + \eta$ ) or PI group ( $\nu + \pi$  on thorax,  $\nu + \pi + \iota$  on abdomen). KAPPA and ETA vary considerably in position relation to each other; therefore, to avoid confusion I have followed Hinton in calling the larger seta KAPPA and the smaller ETA

in all cases. When THETA is present, it is always smaller than ETA and usually nearer to the spiracle.

*Note.* It is useful to remember that any larva (excluding first stage) found on stored food which has a large sclerotized ring enclosing a membranous area at the base of RHO on the mesothorax, combined with white or nearly white cuticles and dark conspicuous oval plates at the base of abdominal setae, is a species of *Ephestia*.

The following three keys are after Hinton & Corbet, Nos 6b and 6c being modified by Mr G. Talbot.

### Key 6b

#### Key to larvae of lepidopterous pests

1. Prolegs short, narrow and often indistinct with only 2 crotchets each. Body 7 mm long or less and always inside a grain (except first stage)

(Fig. 37e) (Gelechiidae) *Sitotroga cerealella*

Prolegs distinct and well developed with many crotchets (2)

2. Two setae in KAPPA group of prothorax *Pyralidae* (3)

Three setae in KAPPA group of prothorax *Tinaeina* (9)

3. KAPPA group of prothorax in a vertical line. First abdominal segment without a sclerotized ring enclosing the base of RHO (5)

KAPPA group of prothorax in nearly horizontal line. First abdominal segment with a sclerotized ring enclosing base of RHO. Spiracles with black or heavily marked rims *Gallerinae* (4)

4. Abdominal spiracles with posterior part of rim distinctly thicker than anterior part. Cuticle of abdomen white. Dorsal setae on abdomen without small oval basal plates *Corcyra cephalonica*

Abdominal spiracles with posterior part of rim only very slightly thicker than

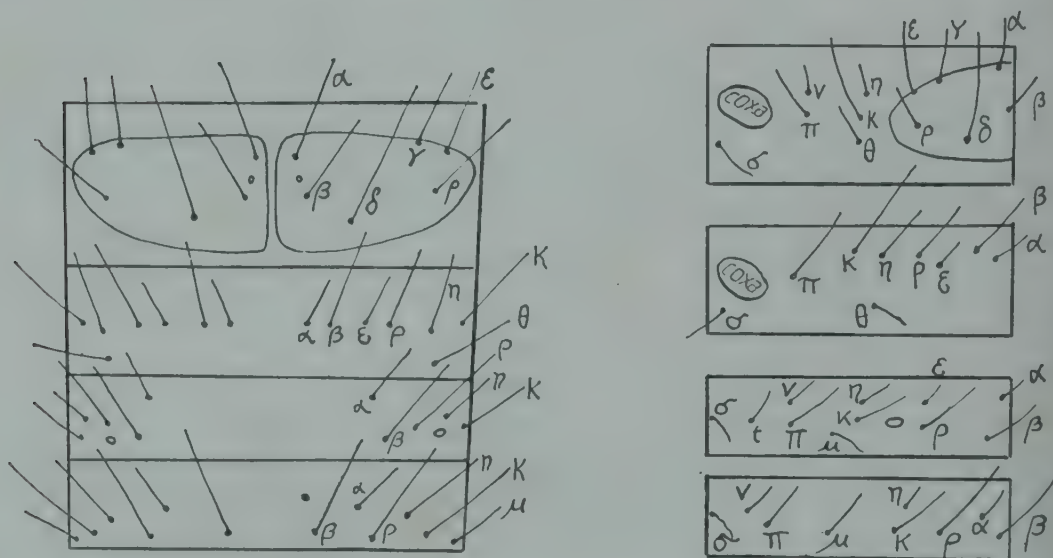


FIG. 58. Chaetotaxy diagram for larvae of stored product moths. (After Hinton, *Bull. ent. Res.* 34, 163.) The segments illustrated are (top to bottom) 1st & 2nd thoracic and 1st & 9th abdominal.

anterior part. Cuticle of abdomen greyish white. Dorsal setae on abdomen (segments 1-8) arise from small oval plates *Paralipsa gularis*

5. Mesothorax with a sclerotized ring enclosing a membranous area at the base of RHO *Phycitinae* (6)

Mesothorax without a sclerotized ring enclosing a membranous area at the base of RHO (Pyralidinae). Head with only 4 distinct ocelli on each side

*Pyralis farinalis*

6. First 8 abdominal segments with only RHO of the 8th segment arising from sclerotized plate (Fig. 37b) *Plodia interpunctella*

First 9 abdominal segments with all dorsal setae (except, sometimes, EPSILON) arising from sclerotized plates (7)

7. Eighth abdominal segment with seta EPSILON separated from spiracle by less than the diameter of the latter. Spiracle as broad or nearly as broad as membranous part enclosed by sclerite of RHO *Cadra cautella*

Eighth abdominal segment with EPSILON separated from spiracle by considerably more than the diameter of the latter (8)

8. Eighth abdominal segment with spiracles not more than  $\frac{2}{3}$  as broad as membranous part enclosed by sclerite of RHO. Prothorax with diameter of spiracle much less than distance between KAPPA group setae. Outer tooth of mandible forming part of outer margin of mandible

(Fig. 37a) *Ephestia elutella*

Eighth abdominal segment with spiracle as broad or broader than membranous part enclosed by sclerite of RHO. Spiracle of prothorax with diameter as great or greater than distance between KAPPA group setae. Outer tooth of mandible, when seen from inner ventral view, does not form part of outer margin of mandible, but is displaced mesally so that this margin is part of second or larger tooth *Anagasta kuhniella*

9. KAPPA and ETA of abdominal segments 1-8 widely separated and in a more or less horizontal line. KAPPA group on prothorax not in a straight line

*Tinaeidae* (11)

KAPPA and ETA of abdominal segments 1-8 close together and in a more or less vertical line. KAPPA group on prothorax in a straight line *Oecophoridae* (10)

10. Head with 4 ocelli on each side. Spiracle of 8th segment sometimes round, but usually with vertical diameter distinctly greater. Labium without a basal depression (Fig. 37c) *Hofmannophila pseudospretella*

Head with 2 ocelli on each side. Spiracle of 8th segment always round. Labium with a large basal pit *Endrosis sarcitrella*

11. Head without ocelli. PI setae of meso- and meta-thorax in a fully oblique or nearly horizontal line. PI group of 9th abdominal segment absent. EPSILON of first 8 abdominal segments dorsal and considerably anterior to spiracle. Spiracles of 7th abdominal segment approximately as large as 8th

(Fig. 37d) *Tineola bisselliella*

Ocelli present (12)

12. Head with 6 ocelli on each side. Spiracles of 7th abdominal segment about  $\frac{3}{4}$  as large as those of 8th. Without a case *Tinea granella*

Head with 1 distinct ocellus on each side. Spiracles of 7th abdominal segment only  $\frac{1}{2}$  to  $\frac{2}{3}$  as large as those of 8th. Always in case shaped like a pillow

*Tinaea pellionella*

### Key 6c

*Key to the larvae of the clothes moths and house moths*

1. Eighth abdominal segment with the first 2 setae below the spiracle close together. Head with 2 or 4 ocelli on each side (2)  
Eighth abdominal segment with the first 2 setae below the spiracle very widely separated. Head with not more than 1 ocellus on each side (3)
2. Head with 4 ocelli on each side. Labium without a pit or sclerotized ring (Fig. 37c) *Hofmannophila pseudospretella*  
Head with only 2 ocelli on each side. Labium with a large but thin sclerotized ring and often also with a distinct pit *Endrosis sarcitrella*
3. Larva in a flattened, portable and very definitely formed fusiform case. Prothorax nearly black *Tinaea pellionella*  
Larva free or in a web or silken gallery but never in a well-formed portable case. Prothorax yellowish or reddish, never blackish (4)
4. Head without ocelli or at any rate ocellar lenses. Spiracles of 8th abdominal segment more or less equal in size to those of 7th (Fig. 37d) *Tineola bisselliella*  
Head with a distinct ocellus on each side. Spiracles of 8th abdominal segment twice or nearly twice as large as those of seventh *Trichophaga tapetzella*

### Key 7a

*Key to adults of beetles commonly occurring as pests of stored food with a few species which attack fabrics and wood*

1. Antennae about  $\frac{1}{2}$  as long as body, borne on prominent tubercle and capable of being reflexed backwards. All tibiae with 2 spurs (Cerambycidae). Domestic wood-borer. Adult 10-20 mm (Fig. 44a) *Hylotrupes*  
Not with this combination of characters (2)
2. Mouthparts at the end of a prominent snout-like projection between the eyes (Curculionidae) (3)  
Head without distinct snout (5)
3. Elytra not quite covering top of abdomen. Pests of food (Fig. 36a, b) *Sitophilus*  
Elytra covering tip of abdomen. Larvae wood-borers (4)
4. Elytra with apical sides dilated and bent upwards. Head deeply constricted just behind eyes (Fig. 44c) *Euophryum*  
Elytra with apical sides not flexed up. Head only slightly constricted behind eyes *Pentarthrum*
5. Elytra leaving at least 1 dorsal abdominal segment exposed (3)  
Elytra completely covering the back (5)
6. Antennae with a distinct 3-segmented club. Elytra not striate (Fig. 35f) *Carpophilus* (Nitidulidae)  
Antennae not clubbed or only indistinctly so. Elytra deeply striate (7)

7. Each eye with a deep indentation extending back from the base of the antennae (Fig. 36d, e) *Bruchidae*  
'Pea or bean weevils'  
Eyes without indentation (*Antheribidae*) (Fig. 36c) *Araecerus fasciculatus*  
'Coffee-bean weevil'
8. Elytra with a blue or blue-green metallic lustre on at least apical four-fifths *Cleridae* (*Necrobia*)  
Elytra never blue or blue green (9)
9. Prothorax with 6 large acute teeth on each side; upper surface with 3 longitudinal ridges. 2.5–3.5 mm. (Dark brown, rather flat) (Fig. 34b) *Oryzaephilus* (*Silvanidae*)  
Prothorax with 2 large teeth on each side, or 1, or none. Back of prothorax with 2 ridges or none (10)
10. Small flat beetles (1.3–5 mm) with 2 longitudinal ridges on back of prothorax, parallel and near to sides. Antennae long and without club (Fig. 34a) *Cryptolestes* (*Cucujidae*)  
Prothorax without longitudinal ridges (11)
11. Hood-shaped prothorax covered with tubercles, rather coarse, especially in front. (Cylindrical and brown; antennae with a large loose 3-segmented club) (Fig. 35h) *Rhizopertha dominica* (*Bostrychidae*)  
'Lesser grain borer'  
Prothorax with a few, very fine, tubercles, or none (12)
12. Prothorax with front corners distinctly toothed or with a very much thickened, nearly smooth, oval, disc-like area, and with a distinct tooth-like projection on the middle of each side (Fig. 35a) *Cryptophagus* (*Cryptophagidae*)  
Prothorax without front corners toothed or thickened (13)
13. Antennae usually more than half as long as the body, none of the segments being broader than the second. Prothorax constricted at the rear to form a kind of waist (except *Gibbium*). Tarsi 5-segmented *Ptinidae* (11)  
(Spider beetles)  
Antennae less than half the body length and apical segments broader than the second, forming a club (16)
14. Elytra bare and shiny (Fig. 36h) *Gibbium*  
Elytra striated and hairy (15)
15. Breadth of elevated part of head between bases of antennae equal to a fourth or less of the first antennal segment (Fig. 36f) *Ptinus*  
Breadth of the elevated part of the head between the bases of the antennae equal to more than half of the 1st antennal segment (Fig. 36g) *Niptus*
16. Antennae with a large, compact, very distinct, 2-segmented club. 3–5 mm. (Narrow, parallel, brown beetles similar in appearance to *Tribolium* but differing in having all tarsi, instead of only the hind tarsi, 4-segmented and the antennal club with 2 instead of 3 or more segments) (Fig. 43g, i) (Lyctidae) *Lyctus*  
'Powder post beetle'
- Antennae with club of 3 or more segments (except some species of *Anthrenus*,

- but the latter are very convex, nearly round beetles covered with white and brown or black scales) or without a distinct club (17)
17. Dorsal surface without hairs or scales visible with a hand lens (18)  
Dorsal surface with scales or hairs (visible, at least, if the specimen is viewed against the light with a hand lens),  $\times 15$  (26)
18. Distinctly flattened beetles, 5–11 mm. Prothorax distinctly separated from the base of the elytra. Tarsi apparently 4-segmented (Fig. 35e)  
(Ostomidae) *Tenebroides*  
(‘Cadelle’)
- Distinctly convex beetles. Base of thorax touching base of elytra (19)
19. Tarsi all 3-segmented. Sides of the prothorax with a flattened, leaf-like edge and the middle slightly depressed. 1.2–2.4 mm (Fig. 35c)  
Lathridiidae (*Enicmus*, *Lathridius*)
- Front and middle tarsi 5-segmented, hind tarsi 4-segmented; prothorax smoothly convex without leaf-like edge, 4 mm or more *Tenebrionidae* (20)
20. Large (20–24 mm) black beetle *Blaps mucronata*  
(‘Churchyard beetle’)
- Less than 18 mm long (21)
21. Brown or black beetle about  $\frac{1}{2}$  inch (14–18 mm) long (Fig. 34c) *Tenebrio*  
(‘Mealworm beetle’)
- Less than 7 mm long (22)
22. Side margins of the head projecting into and nearly dividing the eyes (23)  
Eyes not divided and more or less round (Fig. 34f) *Palorus*
23. Body 4.5–7 mm long, rather broad and black or dark brown in colour (Fig. 34g)  
*Alphitobius*
- Body usually less than 4.5 mm long, narrow, sub-cylindrical and reddish brown in colour. (Except *Tribolium destructor* which is 5–6 mm long and black, but of typical *Tribolium* shape) (24)
24. Antenna shorter than head with a very distinct, compact, 5-segmented club. Hind tarsi with basal segment not as long as the combined length of the two following. 2.5–3 mm (Fig. 34h) *Latheticus oryzae*  
(‘Long-headed flour beetle’)
- Antenna distinctly longer than head, with a compact 3-segmented club, or a loose 4-segmented club, or gradually broadening from the base with no distinct club. Hind tarsi with basal joint as long as combined length of two following (25)
25. Elytra with fine longitudinal ridges, at least at the sides. Males without distinct tubercles on the head and without large, upwardly curved teeth on mandibles (Fig. 34d) *Tribolium*
- Elytra without any longitudinal ridges. Males with 2 prominent tubercles on middle of head and each mandible with a large conspicuous tooth curved upwards (Fig. 34e) *Gnathocerus*
26. Antennae rest in cavities on the prothorax visible from the front. Body tortoise-shaped, conspicuously clothed in alternating patches of white and blackish or brownish scales. 2–4 mm (Dermestidae) *Anthrenus*

- Antennae not received in cavities on the prothorax visible from in front. Body oblong-oval and never with scales (though sometimes with black and white hairs) (27)
27. Head without a median ocellus. Elytra usually striate (28)  
Head with a median ocellus (29)
28. Rather large beetles (5.5–10 mm) densely covered with hairs. (Dermestidae) (Fig. 42a, b) *Dermestes*  
Smaller beetles (2–4 mm) (27)
29. Antennal club 3-segmented. First segment of hind tarsus half as long as second (4–5 mm) (Fig. 42c) *Attagenus*  
Antennal club at least 4-segmented. First segment of hind tarsus much longer than second (1½–3 mm) (Fig. 35d) *Trogoderma*
30. Tarsi all 4-segmented except the front tarsi of males which are 3-segmented. Antennal club 3- or 4-segmented (Fig. 35b) *Mycetophagus, Typhaea* (Mycetophagidae)  
Tarsi all 5-segmented. Antennal club 3- or 8-segmented and always much longer than remainder of antenna. Small brown beetles with the head held under the prothorax and not visible from above *Anobiidae* (31)
31. Antenna with segments 4–10 serrate. Elytra not striate (Fig. 35g) *Lasioderma serricorne* ('Cigarette beetle')  
Antenna with large loose 3-segmented club. Elytra distinctly striate (32)
32. Prothorax with basal middle part, when seen from the side, very strongly humped. 3–5 mm (Fig. 43a) *Anobium punctatum*  
(‘Common furniture beetle’)  
Prothorax with basal middle part not humped. 2–3 mm (Fig. 35i) *Stegobium paniceum* ('Bread beetle')

### Key 7b

*Key to the larvae of five genera of dermestid beetles (after Hinton)*

1. Abdomen with the 10th segment large and forming a distinctly sclerotized ring in which sternum and tergum are fused together as in the preceding segments; 9th segment with 2-dorsal conical processes which are usually large and conspicuous (Fig. 42e) *Dermestes*  
Abdomen with the 10th segment never forming a sclerotized ring, much reduced and entirely membranous or with only the ventral part sclerotized; 9th segment without dorsal conical processes (2)
2. Dorsal surface without spear-headed, segmented hairs. Maxilla with palp 4-segmented (3)  
Dorsal surface with spear-headed, segmented hairs. Maxilla with palp 3-segmented (4)
3. Abdomen with a caudal brush of extremely long, slender hairs (Fig. 42f) *Attagenus*  
Abdomen without a caudal brush of long slender hairs. Thorax and abdomen with marginal setae of tergites club-shaped *Thylodrias*

4. Abdomen with caudal tufts of spear-headed hairs arising from an entirely membranous recess in the outer hind margins of tergites v, vi and vii. No tuft of these hairs on segment viii. Heads of the spear-headed hairs with 5 struts (Fig. 42g) *Anthrenus*

Abdomen with tufts of spear-headed hairs arising from hard portions of the outer hind margins of tergites v, vi and vii; additional tuft present on viii. Heads of the spear-headed hairs with 6 struts (Fig. 35d) *Trogoderma*

### Key 7c

*Key to the larvae of the British genera of domestic wood-boring beetles*

1. Body straight, reaching maximum length of 25–30 mm (6)  
Body distinctly curved, reaching maximum length of 10 mm or less (2)
2. Legs absent *Curculionidae*  
(*Euophryum* or *Pentarthrum*)
- Legs present (3)
3. Legs 3-jointed; 8th abdominal spiracle larger than the others and rather prominent *Lyctus*  
Legs 5-jointed; 8th abdominal spiracle not noticeably larger than the others (4)
4. Spinules present on the hypopleural folds of the first 6 abdominal segments.  
(The hypopleural folds lie on the ventro-lateral edges of the body) *Ptilinus*  
Spinules not present on abdominal segments, as above (5)
5. Spinules absent from 9th abdominal segment (6 mm or less) *Anobium*  
Spinules present on 9th abdominal segment (9 mm or less) *Xestobium*
6. Head and legs well developed. Pronounced tubercles on 3rd and 4th abdominal segments *Nacerdes*  
Head reduced, legs exceedingly small. No unusual tubercles on 3rd and 4th abdominal segments *Hylotrupes*

### CLASSIFICATION OF THE ACARI

There are vast numbers of Acari, only a very small proportion of them being of any public health or domestic importance. The order is generally divided into six sub-orders: (1) Nosostigmata, (2) Holothyroidea, (3) Parasitiformes, (4) Trombidiformes, (5) Sarcoptiformes, (6) Tetrapodili. The first two are small groups of mainly systematic interest and the last one consists of plant gall mites. Accordingly, only (3), (4) and (5) are of interest here. These are very large assemblies, sub-divided into super-cohorts and cohorts (or divisions, groups and grades); and the experts do not always agree on the limit of families and super families. The following scheme will give some idea of the relations of families of mites mentioned in this book.

#### (3) PARASITIFORMES

##### Mesostigmata

##### Ixodides

Dermanyssidae (Blood-sucking mites)

Ixodidae (Hard ticks)

Argasidae (Soft ticks)

(4) TROMBIDIFORMES

**Tarsonemini**

Pyemotidae

**Prostigmata**

Tetranychidae (Orchard mites)

Cheyletidae

Demodicidae (Skin mites)

**Parasitengona**

Trombiculidae (Harvest mites)

(5) SARCOPTIFORMES

**Acaridiae**

Acaridae (Stored food mites)

Sarcoptidae (Mange mites)

Epidermoptidae

**Oribatei** (Beetle mites)

The classification of the Acari is based, in many particulars, on characters which are difficult to see. For this reason, it has not seemed desirable to give keys in this book. Very often, however, the species, or at least the family, may be guessed from the location of the specimens and the general appearance. Some confirmation may be gained from the figures given. Where there is any question of doubt, it is best to preserve the specimens and send them to an expert for identification (see p. 70).



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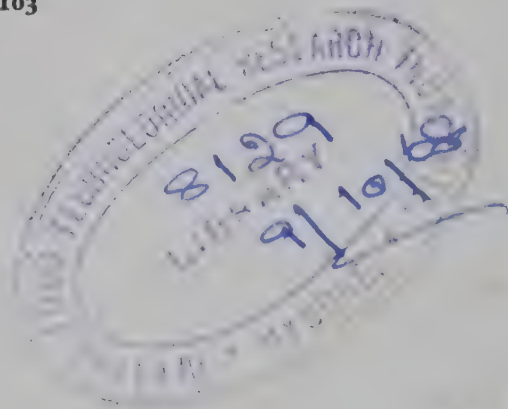
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